Journal of Physical Education and Sport ® (JPES), Vol. 21 (5), Art 342, pp. 2551 - 2559, September 2021
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Interaction of systems of vertical posture regulation and voluntary movement in athletes

OLEKSANDR PRYIMAKOV[1], NATALIJA MAZUROK[2], ANATOLY SKRYPKO[3]
[1]Faculty of Physical Culture and Health Promotion, Szczecin University, POLAND
[2]National Pedagogical Dragomanov University, UKRAINE
[3]State University of Applied Sciences in Kalysz, POLAND

Published online: September 30, 2021
(Accepted for publication September 15, 2021)
DOI:10.7752/jpes.2021.05342

Abstract
Objective: Interrelations of functional systems of balance regulation in vertical posture and control of voluntary movements in athletes specialized in wrestling, weightlifting, and ski jumping were studied. **Material and methods**: The study involved highly skilled athletes aged 20-28. The interrelations between the two regulation systems were studied under conditions of rest, sensory deprivation, changes in posture biomechanical characteristics, and other complications. ***Results*:** The results reflect a strong combined influence of the examined biomechanical and physiological characteristics of the vertical posture on the reproduction accuracy of voluntary movement parameters, the manifestation of the maximum strength of athletes. Among biomechanical factors, the greatest influence on the stability of equilibrium and accuracy of voluntary movement is exerted by the area of standing support, whereas among physiological factors - the displacement amplitude of the body general center of mass (GCM). Correlation, factor, and regression analysis reflect the close relationship between the mechanisms of vertical posture regulation and the examined voluntary movements. A significant impact of various factor interactions on the accuracy of the dosed effort reproduction, the displacement amplitude of voluntary movement along a given trajectory, the manifestation of maximum force on the finger dynamometer, and during jumps on a dynamometer platform was revealed. Each pose parameter influences that of voluntary movement both directly and through interaction with other parameters. The smaller the parameter shifts of posture stability and voluntary movement under the influence of confounding factors and disturbances, the more autonomously and economically they function, the weaker their interrelation, and the higher their functional reserves. ***Conclusions:*** The rearrangement of the posture preceding the movement determines the quality of the subsequent voluntary motion. One of the important criteria for functional reserves of the "posture - voluntary movement" system is the principle of "the least interaction" in the relationship between two regulation systems. Minimization of tremor amplitude and body GCM oscillations is an indirect criterion of functioning quality of the "posture - voluntary movement" system as well as the sensitivity of the proprioceptive sensory system in athletes. Mathematical models reflecting the interrelations of posture and voluntary movement regulation systems can be used to predict the performance of an athlete and be the basis for posture and movement correction in the training process.
Keywords: athletes, regulation, posture, movement, functional reserves, interaction.

Introduction

The process of long-term adaptation of athletes to physical loads is characterized by the increase and improvement of functional reserves (FR), the components of which are morphological, functional, and metabolic reserves. The morphofunctional and metabolic constituents of the reserve capacities of the athletes' body have been studied by numerous scientists (Radziyevsky, Priymakov, Oleshko, & Jashchanin, 2002; Pryimakov, Jashchanin, & Shchegolkov, 2014; Razumov, Pavlov C., & Pavlov A., 2016; Pryimakov, Eider, Nosko, & Iermakov, 2017). The key criteria determining the high level of FR and efficiency of muscular activity have been revealed (Mishchenko, 1997; Wilmore, & Costill, 2004; Dvoenosov, 2009; Platonov, 2015, 2017).

Researchers have found that the improvement of functional capacities (or FR) of the athletes' body in the process of long-term adaptation to physical loads is associated with an increase in the level of development of motor qualities, special work capacity, speed of recovery processes, the efficiency of functioning, and other positive changes (Mishchenko, Lysenko, & Vinogradov, 2007; Pryimakov et al., 2014; Platonov, 2015, 2017).

The authors confirmed the complex nature of morphofunctional and metabolic accumulations determining the FR and sports result in the process of long-term adaptation to physical loads (Platonov, 1988, 2017; Mishchenko, 1990; Bosenko, 2016; Razumov et. al, 2016). At the same time, while there is a large number of works devoted to the issue of increasing the FR of the human body, the reserves of the movement control system represent its relatively poorly documented aspects (Davidenko, 1984; Davidenko, Mozzhukhin, &

Corresponding Author: OLEKSANDR PRYIMAKOV, E-mail: sanaol7.alex@gmail.com

Telegin, 1987; Golubev, Davidenko, Mozzhukhin, & Shabanov, 1987; Pryimakov, & Jashchanin, 2009; Priymakov, Eider, Prisyazhnyuk, & Mazurok, 2020).

The manifestations of the reserves of the balance regulation system in the human vertical posture under various, including extreme conditions, are also insufficiently studied (Gurfinkel, Kotz, & Shik, 1965; Sadovski, Boloban, Nizhnikovski, & Mastalezh, 2011; Pryimakov, Iermakov, Eider, Prysiazhniuk, & Mazurok, 2020; Pryimakov, Eider, Mazurok, & Omelchuk, 2021).

It is characteristic that many authors consider the regulation of the stability of equilibrium in a vertical posture of a human as the regulation of one of the forms of motion manifestation (Gurfinkel et al., 1965; Gurfinkel, & Levik, 1999; Pryimakov, Kozetov, & Kryshkovetsas, 2009).

Retention of equilibrium stability in human vertical posture is characterized by continuous oscillations of the general center of mass (GCM) of the human body in sagittal and frontal planes (Gurfinkel et al., 1965; Boloban, 1990; Gurfinkel, & Levik, 1990; Pryimakov et al., 2009). The frequency and amplitude of micro- and macromovements of the body GCM reflect reflexive mechanisms providing stability of standing in a vertical posture (Gurfinkel at al., 1965; Gurfinkel, Lipshits, Mori, & Popov, 1981; Pryimakov, 1995; Gurfinkel, & Levik 1999; Pryimakov, Eider, & Omelchuk, 2015).

Minimization of deviations of the body GCM in amplitude in the sagittal and frontal projections is referred by the authors to one of the most important criteria for stability of equilibrium in the vertical posture (Gurfinkel et al., 1965; Gurfinkel et al., 1981; Boloban, 1990). It is characteristic that a decrease in the amplitude of the body GCM oscillations correlates with increased frequency of leg tremor as a background component of slow body GCM displacements (Gurfinkel et al., 1965; Pryimakov, 1995; Pryimakov et al., 2015).

As shown in the studies of Gurfinkel et al. (1965), Gurfinkel, & Levik (1999) as well as in our earlier studies (Pryimakov, 1995; Pryimakov et al., 2015), high stability of vertical posture is achieved through a hierarchically organized functional system the structural and functional components of which are visual, vestibular, proprioceptive sensory systems, locomotor system, control nerve centers. The harmonization of their interrelations and coordination in the process of adaptation to physical loads constitute the basis for improving and enhancing the quality of the balance function before and during the implementation of voluntary movements (Pryimakov, 1995; Sadovski et al., 2011).

However, the interrelations of different components of vertical posture regulation system and the system of voluntary movement control, their reserves in the process of improvement in extreme conditions of athlete body functioning, remain insufficiently studied.

To the least examined aspects of the issue of increasing the reserve capacities of the human body in extreme conditions, one should refer the reserves of the interaction of two regulation systems: the system of balance regulation in the vertical posture and the system of voluntary movements' control.

The system approach in biological studies envisages the investigation of not only the regulation mechanisms of each functional system separately but also the mechanisms of their interaction in the process of integration to ensure the efficiency of muscular activity in sport.

Insufficient coverage of the majority of these issues in the literature, their extreme importance for the theory and practice of physical education and sport are indicative of the relevance of the considered problem and served as the basis for choosing the direction and objective of the study.

The objective of this work is to study the relationship between the system of stability of equilibrium regulation in orthograde posture and the system of control for local voluntary movements in athletes.

Material and methods

Participants. The following athletes of the national team of Ukraine were examined: 12 weightlifters aged 20-28, 14 wrestlers aged 22-27, and 12 ski jumpers aged 20-25.

The study protocol was approved by Ethics Committee University. The research was fulfilled in compliance with the WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects (2013).

Procedure. Athletes specialized in wrestling participated in studies aimed at investigating the relationships between the parameters of posture stability and the accuracy of the reproduction of the amplitude and duration of given displacements of the body general center of mass (GCM) on a stabilograph, efforts on a finger dynamometer. Those specialized in ski jumping and weightlifting took part in studies focused on examining the dependencies of spatiotemporal and strength characteristics of the jump on a dynamometer platform upon the physiological and biomechanical characteristics of the posture.

A complex technique of combined multiparametric registration of posture physiological and biomechanical characteristics and parameters of voluntary movement was used in the work. The block of the complex technique consisted of separate techniques: a) registration of maximum and dosed efforts on a finger dynamometer; b) registration of oscillations of the athletes' body GCM on a stabilograph; c) registration of arm and leg tremor (tremorometry); d) registration of efforts and height of standing jumping up on a dynamometer platform; e) registration of angular indices of the knee and hip joints in various postures (goniometry); f) registration of accuracy of reproducing specified displacements of the body GCM on a stabilograph.

The study of inter- and intrasystem interrelations of two functional systems was based on the analysis of interactions of parameters of equilibrium stability in a vertical posture and those of performed voluntary movements such as accuracy of reproducing voluntary movement amplitude on the stabilograph and dosed effort on the finger dynamometer, strength and height of a jump.

The following were considered as the parameters of the "final adaptive results" (according to Anokhin, 1979) of each functional system: 1) the body GCM oscillations and the amplitude of the leg tremor being the integral components of the active human posture (Gurfinkel et al., 1965; Boloban, 2014; Pryimakov, 2016); 2) error values during reproduction of the amplitude and duration of the body GCM displacements along a given trajectory on a stabilograph; 3) dosed and maximal efforts on a finger tensodynamometer; 4) height of standing jumping up (h), and indices of the developed efforts (Fmax) during taking-off of a dynamometer platform.

Statistical analysis. Statistical software package STATISTICA 13.5 was used to process the experimental material. Methods of variation statistics, correlation, regression analysis, and analysis of variance were used (Borovikov, & Ivchenko, 2006).

Results

The experimental material analysis demonstrated that the magnitudes of errors committed during reproducing various components of voluntary motion (body GCM displacements along a given trajectory on the stabilograph, and dosed efforts on the finger dynamometer) show high correlations with the amplitude of tremor and oscillations of the body GCM registered at rest.

Table 1 shows correlation coefficients and regression equations reflecting the interrelations of tremor amplitude and involuntary oscillations of the GCM with the magnitudes of errors in reproducing the amplitude and time of the GCM displacements along a given trajectory on the stabilograph, as well as the efforts on the finger dynamometer (50% of Fmax) in wrestlers (Table 1).

Table 1. Correlation coefficients and regression equations of relationships between posture stability parameters and the accuracy of reproducing the parameters of voluntary motion in wrestlers.

Parameters of vertical posture stability	Error during reproducing voluntary motion components:					
	Amplitude of GCM displacements along a given trajectory, c.u.		Time of GCM displacements along a given trajectory, s		Dosed effort (0,5 F max), kg	
	r	y	r, P	y	r, P	y
Tremor amplitude at rest, c.u.	0,643 <0,05	1,04x-1,07	0,833 <0,01	0,04x-0,02	0,901 <0,01	2,23x-8,2
Amplitude of GCM oscillations at rest, mm	0,721<0,05	1,7+1,9x	-	-	0,787 <0,05	1,9+0,22x
Tremor amplitude during voluntary motion, c.u.	0,881 <0,01	1,13x-2,1	0,976 <0,01	0,036x-0,004	0,921, P<0,001	-

The results presented in the Table indicate that tremor amplitude at rest in the initial posture exhibits high positive correlations with error magnitudes during subsequent reproduction of the components of wrestlers' voluntary movement (Table 1).

The relationship between the amplitude of leg tremor and the accuracy of reproducing the parameters of voluntary movement and dosed effort increases directly in the process of voluntary movement realization.

This suggests that the process of voluntary movement realization occurs in the face of the intensified interconnection of two regulatory systems - the system of regulation of equilibrium stability in vertical posture and the system of voluntary motion control (spatial, temporal, and strength parameters).

The high dependencies between the indices are modeled by means of regression linear models of the first order, Modeling through the use of the equations developed and presented in Table 1 demonstrated that a 20% increase in the amplitude of tremor in the initial posture is accompanied by a 75.6% increase in errors during reproducing the effort on the finger dynamometer (y=2.23x-8.2). An increase in the amplitude of body GCM oscillations by 5 mm in the initial posture is accompanied by a decrease in the accuracy of reproducing the amplitude of voluntary movement by 84.8% (y=1.7+1.9x), dosed effort - by 37% (y=1.9+0.22x).

Tremor amplitude, as an integral component of active posture (Gurfinkel et al., 1965), also exhibits a high positive correlation with the value of maximum effort on the finger tensodynamometer ($r = 0.921$, $P<0.001$).

It is noteworthy that the tremor registered during movement exhibits a greater correlation with the magnitudes of errors during reproducing the parameters of voluntary movement than that registered in the initial posture, i.e., before the movement onset (Table 1). This indicates an increase in the relationship between the two regulatory systems in the process of movement.

To analyze the physiological mechanisms underlying the interaction between the two regulation systems, the single and two-factor analysis of variance was performed and partial correlation coefficients were calculated.

The analysis of variance showed that in 78 ± 6% of cases the accuracy of effort reproduction depended on the tremor amplitude, and only in 22% of cases on the influence of factors not accounted for in the study.

Maximum hand strength is weakly dependent on the amplitude of the initial tremor (η^2 = 0.06 ± 0.024, P>0.05) and quite strongly on the body mass of the athlete (η^2 = 0.616 ± 0.024, P<0.01). Athlete body mass significantly affects tremor amplitude (η^2 = 0.547 ± 0.05, P<0.01), which, in its turn, influences the accuracy reproduction of dosed effort reproduction (η^2 = 0.780 ± 0.06, P<0.01).

An increase in athlete body mass is associated with an increase in tremor amplitude, maximum hand strength (Fmax), and, simultaneously, with a decrease in the accuracy of muscle differentiation during dosed effort reproduction (0.5 Fmax).

Error magnitudes during the dosed effort reproduction show high correlations with Fmax (r = 0.889, P<0.01), athlete body mass (r = 0.847, P<0.01), and tremor amplitude (r = 0.981, P<0.01). However, calculation of partial correlation coefficients and analysis of variance demonstrated that the accuracy of the dosed effort reproduction is not directly related to either the body mass of the athlete or his ability to manifest maximal efforts. The high correlations of Fmax and the athlete body mass with the magnitudes of errors during the dosed effort reproduction are manifested through their interaction with the tremor amplitude.

The data presented in Table 2 indicate that the stability of the orthograde posture and the accuracy of reproducing the parameters of voluntary movement are different in the postures that differ in the standing support area, the knee joint angle, and the participation of the visual sensory system in its regulation.

Table 2. The amplitude of body GCM oscillations and the magnitudes of errors during the parameters of voluntary movement reproduction in wrestlers under different conditions of vertical posture maintenance

Knee joint angle, degr.	Standing support area:	Visual sensory system:	Amplitude of GCM oscillation (mm)	Error magnitudes:	
				Effort reproduction, kg	Amplitude reproduction, mm
	cm^2		X ± м	X ± м	X ± м
180°	1039±60	eyes open	2,3 ± 0,3	1,35± 0,2	6,8± 0,6
		eyes closed	5,7 ± 0,5	3,6 ± 0,4	36 ±1,8
	239±23,5	eyes open	8,2 ± 0,7	2,9 ± 0,4	33 ± 1,0
		eyes closed	14,8 ± 0,8	4,5 ± 0,6	52± 2,2
105°	1039±60	eyes open	5,9 ± 0,6	5,2 ± 0,7	28± 1,5
		eyes closed	6,2 ± 0,7	3,3 ± 0,5	32± 1,5
	239±23,5	eyes open	14,8 ± 1,1	4,5 ± 0,5	52± 2,4
		eyes closed	19,7 ± 1,4	6,9 ±0,7	37± 2,0

Certain parallelism in the shifts of both orthograde posture parameters and movement accuracy is noticeable in Table 2.

A three-factor analysis of variance showed that both posture stability and the accuracy of reproducing the components of voluntary movement exhibit high dependencies on the combined effect of the knee joint angle, the standing support area, and the visual reafference (Table 3), i.e., biomechanical and functional parameters of the system of balance regulation in the vertical posture.

Table 3. Dispersion coefficients of three-factor analysis of the impact of biomechanical posture characteristics and visual afferentation on the stability of equilibrium and the accuracy of reproducing the specified displacements of body GCM (ΔA) and dosed effort (ΔF).

Dependent indices:	Determining factors:				
	Knee angle	Support area	Visual afferentation	Interaction effect	Combined effect
Amplitude GCM η^2	0,119	0,685	0,113	0,068	0,985
±m	0,0009	0,0009	0,0009	0,0009	0,006
P	<0,001	<0,001	<0,001	<0,001	<0,001
ΔA η^2	0,039	0,436	0,119	0,395	0,989
±м	0,0007	0,0007	0,0007	0,005	0,005
P	P<0,001	<0,001	<0,001	<0,001	<0,001
ΔF η^2	0,346	0,174	0,116	0,293	0,929
±m	0,004	0,004	0,004	0,004	0,03
P	P<0,001	<0,001	<0,001	<0,001	<0,001

Of the determining factors, the standing support area has the greatest influence on the changes of dependent indices. Its reduction is associated with the decrease of the stability of equilibrium and the accuracy of reproducing the parameters of voluntary movement.

Knee joint angle and visual reafference have less impact on the stability of equilibrium and accuracy of movement parameter reproduction. Nevertheless, their influence is statistically significant (Table 3).

For instance, a decrease of the knee angle by 75° can explain the deterioration of equilibrium stability in 11.9 ±0.09% of cases, the accuracy of motion amplitude reproduction in 3.9 ± 0.07%, effort in 34.6 ± 0.4% of cases. Exclusion of the visual afferentation causes deterioration of equilibrium stability in 11.3 ± 0.09% of cases, the accuracy of effort reproduction in 11.6 ± 0.4% of cases, and motion amplitude in 11.9 ± 0.07% of cases. In some positions, the process of muscle effort differentiation occurs more accurately in the absence of visual reafference, i.e., only based on proprioceptive information (Table 3).

The accuracy of reproducing the voluntary movement amplitude also depends on the interaction of the studied factors. The impact of their interaction can explain 39.5 ± 0.5% of changes in the amplitude of voluntary motion and 29.3 ± 0.4% of the effort. In addition, 6.8 ± 0.09% of changes in the amplitude of body GCM oscillations can also be explained by the interaction of the studied factors.

The unidirectionality in the shifts of body GCM oscillations, errors in the reproduction of the voluntary movement parameters in the conditions of the reduction of the standing support area, and exclusion of vision was expressed in high correlation coefficients between them (r = 0.877, P<0.00001 and r = 0.788, P<0.0003). The form of the correlations is close to linear (Fig. 1).

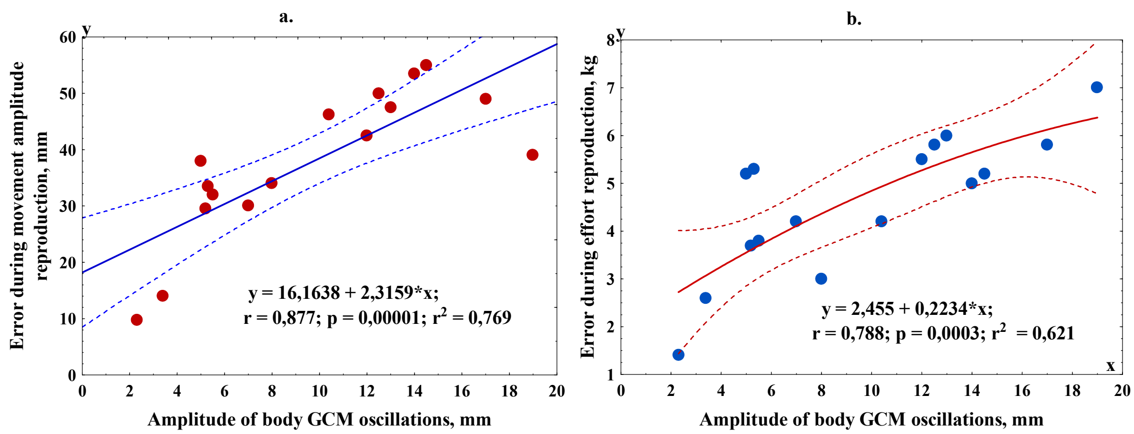

Fig.1 Regression models and empirical values of errors during reproducing the amplitude of voluntary movement (a) and effort (b) from the amplitude of the body GCM displacements in orthograde posture in wrestlers.

The dynamics of the studied indices, correlation and determination coefficients, theoretical regression lines, and the distribution of empirical data indicate the presence of different dependencies between the indices.

For instance, with the deterioration of posture stability with a decrease in the standing support area, knee angle, and functional deprivation of visual afferentation, the accuracy of reproducing the parameters of voluntary movement decreases. Modeling showed that a 20% increase in the amplitude of body GCM oscillations is accompanied by a 15.4% increase in the error of reproducing the amplitude of voluntary movement (ΔA), and by 11.3% in the effort at half of the maximum (ΔF) on the wrist dynamometer.

Analysis of variance results presented in Table 4 indicates that changes in the amplitude of body GCM oscillations, as a parameter of posture stability, can explain changes of 58.0 ± 5% (P<0.01) of error variance during reproducing amplitude and 42.9 ± 8% (P<0.05) of voluntary movement efforts.

Table 4. Influence of amplitude of body GCM displacements on the accuracy of reproducing the parameters of voluntary movement.

Dependent indices:	Analysis of variance parameters:			
	η^2	±m	F	P
ΔA (motion amplitude)	0,580	0,05	10,3	<0,01
ΔF (effort)	0,429	0,08	5,6	<0,01

Studies involving weightlifters and Nordic combined skiers demonstrated that some parameters of voluntary movement performed in vertical posture (jumping up height and effort) depend on the knee joint angle.

In particular, while performing a jumping test, the jumping up height (h) reaches the maximum indices when the knee angle constitutes 72º. The maximum strength of taking-off (Fmax) reaches maximum indices at values of the knee angle in the range from 107º to 130º (Fig. 2).

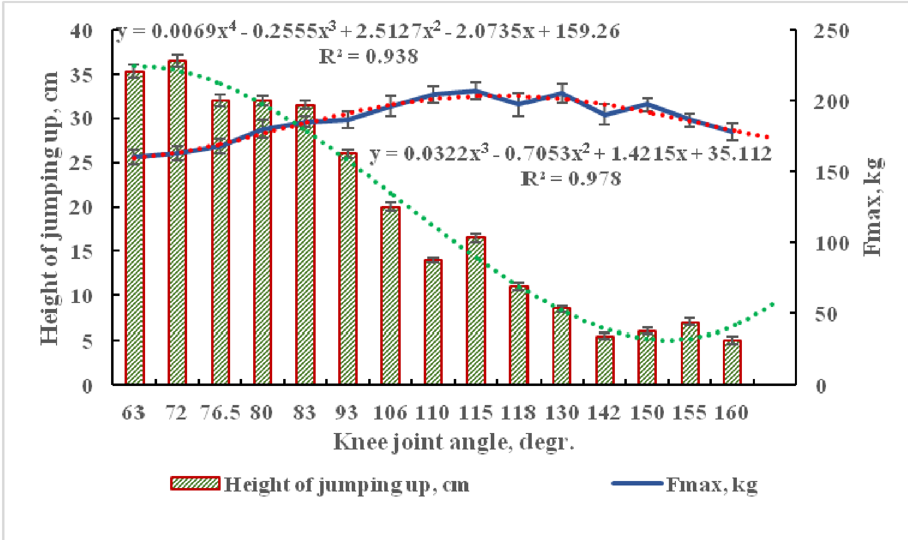

Fig. 2 Height of jumping up and effort (Fmax) during the execution of standing upward jump at different knee joint angles.

Performance of the jump at other values of the knee angle in the vertical stance is less effective.

Regression equations, correlation, and determination coefficients, presented in the figure, reflect the high informative value of the developed mathematical models.

Discussion

The integrative character of athletes' motor activity is provided by various mechanisms, with participation and interaction of physiological and functional body systems.

In the works of Platonov, (2017), Mishchenko et al. (2007), Sadovski et al. (2011) the researchers show that the analysis of the integrative activity of the athletes' body in a solution of motor tasks is effective if it is based on a systemic and comprehensive approach (Sudakov, 1996; Anokhin, 1997; Novikov, 2016).

Solving the problem of the human body functional reserve increase and improvement from the standpoint of the system approach envisages the study of both the partial role of individual physiological systems and the analysis of their combined and interacting influence in the process of combining into different functional systems (Pryimakov, 1995; Anokhin, 1997; Platonov, 2017; Pryimakov et al., 2017).

The hierarchical structure of such associations provides the efficiency of motor tests (Boloban, 1990; Sadovski et al., 2011), compensatory responses under the action of confounding factors and disturbances, high level of special work capacity, and sports result (Mishchenko et al., 2007; Pryimakov at al., 2009; Pryimakov et al., 2015; Litvinenko, Sadowski, Niznikowski, & Boloban, 2015).

The experimental material presented in the given work and that obtained earlier (Pryimakov, & Dotsenko, 2008; Pryimakov et al., 2015; Samokish, & Pryimakov, 2017; Pryimakov et al., 2020), was analyzed, summarized, and compared with the materials of researchers, who dealt with the problem of increasing the reserve capacities of the athlete body (Mishchenko, 1990; Dotsenko, 2004; Platonov, 2017; Samokish, Bosenko, & Pryimakov, 2017).

The emphasis was made on the analysis of FR of the motion control system of different coordination structure and the system of vertical posture regulation (Boloban, 2012; Pryimakov et al., 2015), their interconnections (Martynenko, 1994; Boloban, 2012; Pryimakov, 2020; Litvinenko, Sadovovsky, & Boloban, 2015; Pryimakov et al., 2015) in the process of athletes adaptation to physical loads.

Analysis of the interaction between the two functional systems demonstrated that the voluntary movement execution depends on the structure and character of control for the previously assumed posture in wrestlers, weightlifters, and Nordic combined skiers.

Our findings are consistent with the results of the studies of Boloban (1990), Boloban, Litvinenko, & Niznikowski (2012), Chertikhina (2013), Litvinenko et. al. (2015) carried out on gymnasts. On the other hand, they update them with the revealed specificity of interaction between the system of equilibrium regulation in a vertical posture and the system of regulation of voluntary, including precision movements, in athletes specialized in wrestling (Pryimakov, 1995) and shooting (Pryimakov et al., 1915). The criteria of interaction between the two FS are defined, and the indices correlating with the efficiency of solving motor tasks are revealed. From these perspectives, the identified peculiarities are new.

Analysis of the regulation of posture stability and quality of voluntary movement execution, their interrelations in conditions of various complications and disturbances allowed investigating the mechanisms and reserves of compensation during regulation of two FS under different conditions.

Physiological tremor and the body GCM oscillations, as integral components of actively functioning system of vertical posture stability regulation, reflecting the quality of its regulation mechanisms, influence the accuracy of voluntary movement parameter reproduction: dosed efforts, spatial and temporal parameters of movement. The tremor amplitude exhibits a high correlation not only with the accuracy of reproducing the biodynamic characteristics of the voluntary movements performed on the finger dynamometer and stabilograph but with the value of the developed maximum efforts as well.

The ability to manifest maximal efforts during compression of the hand dynamometer and performance of vertical jumps on the dynamometer platform weakly depends on the amplitude of the body GMC displacements, i.e., on the stability of the vertical posture.

The obtained results give ground to consider low values of the arm tremor amplitude and the amplitude of high-frequency oscillations of the body GCM in the vertical posture as the key criteria of the quality and reserves of its functioning before voluntary movement performance.

This is in agreement with the ideas of the researchers who have dealt with the problem of the regulation of vertical posture stability (Gurfinkel et al., 1965; Gurfinkel, & Levick 1990, 1999; Boloban, 1990, 2013), its interrelations with the quality of performing voluntary movements by athletes (Boloban, 1990; Sadovski et al., 2011; Boloban, Litvinenko, & Nizhnikovski, 2012), physical fitness of children (Żukowska, Szark-Eckardt, Muszkieta, & Iermakova, 2014).

At the same time, the obtained results supplement the authors' research material by revealing the functional capacities of the human body from the standpoint of concretizing the mechanisms of control and interaction of two systems of regulation – of posture and voluntary movement.

In addition, the criteria of functioning and interaction of vertical posture and parameters of the voluntary movement were specified and supplemented:

a) the smaller the amplitude of physiological tremor and high-frequency oscillations of the body GCM, the better the FS of balance regulation functions;

b) the less the increase in the amplitude of tremor and body GCM oscillations in the process of posture complication, the smaller the magnitudes of errors during reproducing the dosed effort, spatial and temporal characteristics of local voluntary movement;

c) the fewer changes in the parameters of posture stability and voluntary movement under the action of confounding factors and hindrances (deprivation of vision, fatigue, reduction of standing support area, etc.), the weaker the relationship between two functional systems, the more autonomous and economic they function, the higher their functional reserves.

This is in agreement with the principle of the "least interaction" manifested in the interrelations of complex control systems in the process of their improvement (Gelfand, Gurfinkel, & Zetlin, 1962; Zetlin, 1969).

The principle of "least interaction" in the relationship between the two FS can also be considered one of the important criteria of functional reserves of the new structural and functional organization "posture - voluntary movement" formed in the process of training (Pryimakov, 1995; Pryimakov et al., 2015). It is formed and improved in the process of learning various skills from different postures.

These studies, as well as our earlier studies of wrestlers (Pryimakov, 1995) and shooters (Pryimakov et al., 2015), students (Pryimakov, & Dotsenko, 2008) showed that posture rearrangements preceding the motion determine the quality of the subsequent voluntary movement.

It is characterized both by innate responses of the bulbo-spinal level, manifested in the form of low-amplitude, high-frequency oscillations of the body GCM, arm and leg tremor, which are difficult to control, and by reactions of a relatively slow type that occur in sagittal and frontal projections with greater amplitude, and are manageable, which is an important feature of the supraspinal organization of complex movements (Gurfinkel et al., 1965; Pryimakov, 1995; Pryimakov et al., 2015).

As far as the quality of posture regulation and the accuracy of muscular effort dosage depend on the functional state of the motor sensory system (Gurfinkel, & Levick, 1999), and because high correlations were revealed between tremor amplitude and errors in muscle differentiation, the amplitude of physiological tremor can be used as an indirect prognostic criterion of the proprioceptive sensory system sensitivity in athletes.

Conclusions

The results reflect the close interaction between the mechanisms of regulation of vertical posture and voluntary movement in athletes.

They reflect a strong combined effect of posture biomechanical and physiological characteristics on the accuracy of reproducing the parameters of voluntary movement, the manifestation of maximum muscular strength. Among biomechanical factors, the greatest influence on the stability of equilibrium and accuracy parameters of voluntary movement is exerted by the standing support area, whereas among physiological ones - the amplitude of body GCM displacements.

A significant impact of various factor interactions on the reproduction accuracy of the dosed effort and the amplitude of voluntary movement was revealed.

Each posture parameter influences the parameters of voluntary movement both directly and through interaction with other parameters.

The low indices of arm tremor amplitude and the amplitude of high-frequency oscillations of the body GCM in the vertical posture represent the key criteria for the quality and reserves of its functioning before the execution of a voluntary movement.

Mathematical models reflecting the interrelations of posture and voluntary movement control systems can be used to predict the performance of an athlete and be the basis for posture and movement correction in the training process.

Conflict of interests. The authors declare that there is no conflict of interest.

References

Anokhin P.K. (1979). System mechanisms of the higher nervous activity. M.: Science.

Boloban V.N. (1990). System of training movements in difficult conditions to maintain stability statodynamic. Doctoral dissertation. Kiev. 442 p.

Boloban V., Litvinenko Y., Niznikowski T. (2012). System stabilography: methodology and methods for measuring, analyzing, and evaluating statodynamic stability of athlete body and system of bodies. *Science in the Olympic sport, 1,* 27–35.

Boloban V.N. (2013). The regulation of body posture athlete. Kiev: Olympic Literature.

Borovikov V.P., Ivchenko G.I. (2006) Prognostication in the system of Statistica in theenvironment of Windows. Moscow: Finances and statistics.

Bosenko A.I. (2016). Biological research methods in physical education and sport: Teaching guide. Odesa: K.D. Ushinsky PNPU.

Chertikhina N.A. (2013). Integrated development of vestibular stability in rhythmic gymnastics at the initial training. PhD thesis. Volgograd. 24 p.

Davidenko D.N. (1984). Methodological approaches to studying athletes' functional reseves. *Physiol. Problems of adaptation*. Tartu: Minvuz USSR, 118–119.

Davidenko D.N. Mozzhukhin, A.S., Telegin V.V. (1987). Physiological reserve mobilization during strenuous muscular activity. *Human Physiology*, V,13(1), 127-132.

Dotsenko E.N. (2004). Reserve capacities of motion control system of different coordination structure in female students of special education department of the university. *Pedagogics, psychology and medico-biological issues of physical education and sport*. *Kharkiv-Donetsk,* 4, 36-41.

Dvoyenosov V.GΓ. (2009). Features of adaptation responses of cardiorespiratory system, gas exchange and cardiac rhythm regulation in rock climbers during competitions. *Theory and practice of physical culture,* 7, 87–91.

Gelfand I.M., Gurfinkel V.S., Tsetlin M.L. (1962). On management tactics for complex systems in relation to the physiology. *Biological aspects of cybernetics*. M.: USSR AS Publishing House. pp. 66–73.

Golubev V.N., Davidenko D.N., Mozzhukhin A.S., Shabanov A.I. (1987). Assessment of functional reserves in motor control system. *Systemic mechanisms of adaptation and mobilization of organism's functional reserves in the process of achievement of highest sportsmanship*. Leningrad, pp. 12-18.

Gurfinkel V.S., Kots Y.M., Shik M.L. (1965). Human posture regulation. M.: Science.

Gurfinkel V.S., Lipshits M.I., Mori S., Popov K.E. (1981). Body position stabilization is the main task of posture regulation. *Human physiology,* Vol 7, 3, 400-410.

Gurfinkel V.S., Levik Y.S. (1999). Muscular reception and generalized description of body position. *Human physiology*, vol.25(1), pp. 87 – 97.

Litvinenko Y.V., Sadowski Jerzy, Niznikowski Tomasz, Boloban V.N. (2015). Static-dynamic stability of the body gymnasts qualifications. *Pedagogics, psychology, medical-biological problems of physical training and sports.* Vol.1, pp. 46-51. http://dx.doi.org/10.15561/18189172.2015.0109

Martynenko I.G. (1994). Research on interaction of the systems of human head motion control vertical posture regulation. Ph.D. diss. SPb. 200 c.

Mishchenko V.S. (1990). Functional potentials of athletes. Kiev: Health.

Mishchenko V.S, Lysenko E.N, Vinogradov V.E. (2007). Reactive features of cardiorespiratory system as the reflection of adaptation to strenuous physical training in sport. Kiev: Scientific World.

Novikov D.A. (2016). Laws, regulations, and principles of management. *Innovation and management, 1,* 44 – 53.

Platonov V.N. (1988). Adaptation in sport. K.: Health.

Platonov V.N. (2015). System of athletes' preparation in the Olympic sport. General theory and its practical applications. K.: Olympic literature. Book 2.

Platonov V.N. (2017). Theory of adaptation and functional systems in the development of the system of knowledge in the field of athletes' training. *Science in the Olympic sport, 1,* 29-47.

Pryimakov O.O. (1995). The relationship between mechanisms of posture stability regulation and arbitrary precision movement in athletes. *Physiological journal*, *41,* (3-4), 23-28.

Pryimakov A.A., Dotsenko E.V. (2008). The use of means and methods of nontraditional health-related systems to increase the motor system reserve capacities in female students of special medical group. *Ecologo-*

biological issues of education and upbringing. Odesa: *South-Ukrainian national pedagogical university named after K.D.Ushinsky*, pp. 124-130.

Pryimakov O.O., Kozetov I.I., & Kryshkovetsas E. (2009). Reserve capabilities of the local movement control system during physical culture and sports. *Bulletin of Chernihiv State Pedagogical University. ChDPU them. T.G. Shevchenko*. Chernihiv, V.65, pp. 256-259.

Pryimakov O., Jashchanin J., Shchegolkov A. (2014). Criteria of athlete neuromuscular system reserve capacities during performance of speed-strength work. *Central European Journal of Sport Sciences and Medicine*, 6 (2), pp. 35–43.

Pryimakov A.A., Eider E., Omelchuk E.V. (2015). Stability of equilibrium in upright stance and voluntary motion control in athletes-shooters in the process of ready position and target shooting (2015). *Physical education of students*, 2015, n.1, pp. 36-42. http://dx.doi.org/10.15561/20755279.2015.0106.

Pryimakov AA, Eider E, Nosko M.O, Iermakov SS. (2017). Reliability of functioning and reserves of system, controlling movements with different coordination structure of special health group girl students in physical education process. *Physical education of students*, 2:84–89. https://doi.org/10.15561/20755279.2017.0206

Pryimakov A.A, Eider Erzy, Prisazhniuk S.I., Mazurok N.S. (2020). Functional reserves of the system of voluntary motion control during strenuous muscular activity. *Scientific bulletin of the South-Ukrainian national pedagogical university named after K.D. Ushinsky*, Odesa, *3*(132), 31-40. https://doi.org/10.24195/2617-6688-2020-3.

Pryimakov O, Iermakov S, Eider J, Prysiazhniuk S, Mazurok N. (2020). Physiological criteria of functional fitness and determinants of physical work capacity of highly skilled wrestlers. *Physical Education of Students*, 24(4), 205–212. https://doi.org/10.15561/20755279.2020.0403

Pryimakov Oleksandr, Eider Jerzy, Mazurok Natalija, Omelchuk Olena (2021). Functional reserves and reliability of controlling stereotyped motions of different coordination structures in athletes during muscular activity. *Journal of Physical Education and Sport* ® (JPES), vol. 21 (2), Art 102, pp. 819 – 828. http://dx.doi.org/10.7752/jpes.2021.02102

Radziyevsky A., Priymakov A., Oleshko V., Jashchanin N. (2002). On accumulation, expenditure and redistribution of functional reserves in human body. *Science in the Olympic sport*, Kiev, 2,110-119.

Razumeiko N.S. (2015). Early diagnosis of junior school age children’s posture disorders. *Pedagogics, psychology, medical-biological problems of physical training and sports*, 12:96–102. http://dx.doi.org/10.15561/18189172.2015.1215

Razumov A.N., Pavlov S.E., Pavlov A.S. (2016). Cross-adaptation” and the laws of “trainability transfer”. *Psychologo-pedagogical and medico-biological issues of physical culture and sport (Russian journal of physical education and sport).* Naberezhny Chelny state pedagogical university, 11, vol. 3, 42-52.

Sadovski E., Boloban V., Nizhnikovski T., Mastalezh A. (2011). Regulation of the posture of young athletes when solving motor tasks for body stability in balance. *Theory and practice of physical culture,* vol. 8, pp. 37 – 42.

Sadowski J., Boloban V., Wiśniowski W., Mastalerz A., Niźnikowski T., Niźnikowska E. (2007). Skuteczność regulacji równowagi ciała gimnastyków pod czas wykonania testów motorycznych. *Kierunki doskonalenia treningu i walki sportowej diagnostyka*, Warsaw, AWF, vol. 4, pp. 100-104.

Samokish I.I., Pryimakov O.O. (2017). Understanding the essence of human functional reserves by specialists of various fields of science. *Scientific jornal of M.P. Dragomanov National pedagogical university. Series 15. «Scientific and pedagogic issues of physical culture and sport»*. Kyiv: NPU. Iss. 3K (84) 17, 428-431.

Samokish, I., Bosenko, A., Pryimakov, O., Biletskaya, V. (2017). Monitoring System of Functional Ability of University Students in the Process of Physical Education. *Central European Journal of Sport Sciences and Medicine,* 17 (1), 73–78. https://doi.org/10.18276/cej.2017.1-09 .

Sudakov K.V. (1996). Theory of functional systems. Moscow: Science.

Tsetlin M.L. (1969). Studies on automata theory and biological system modeling. Moscow: Science.

Wilmore, J.H., & Costill, D.L. (2005). Physiology of exercise and sport. Champaign, IL: Human Kinetics.

Żukowska Hanna, Szark-Eckardt Mirosława, Muszkieta Radosław, Iermakova Tetiana (2014). Characteristics of body posture in the sagittal plane and fitness of first-form pupils from rural areas. *Pedagogics, psychology, medical-biological problems of physical training and sports*, 2014, vol. 7, pp. 50-60. https://doi:10.6084/m9.figshare.1015583