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ORIGINAL ARTICLE

CONTENTS

Assessment of students' body response to physical exertions based on quantitative criteria of resistance

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ABSTRACT

Aim: To investigate the biomechanical indicators of the statokinesiogram to assess coordination-related stability (balance) criteria in students before and after physical exertion.

Materials and Methods: The research, which was conducted in 2024-2025, involved 30 male students of the 1st-2nd academic years of the main medical group. Methods: analysis and generalization of literary sources, method of computerized stabilography (statokinesiometry), methods of mathematical statistics. The complicated Romberg stance assessed students' balance.

Results: The biomechanical indicators of the statokinesiogram were investigated to assess the criteria of students' stability before and after physical exertion during physical education training sessions. Students demonstrate stable statokinesiogram indicators with a significantly unchanged ellipse area of the COM oscillations before and after exertion (S_{Ells} – 3606 and 4004 mm^2; α > 5 %). The leading role of proprioceptive, amplitude-frequency characteristics of the body's COM oscillations in balance control has been proven.

Conclusions: It has been established that maintaining balance by a student is a dynamic phenomenon that requires continuous body movement, which is the result of the interaction of vestibular and visual analyzers, joint and muscle proprioception, central and peripheral nervous systems. The cause of body mass center fluctuations is respiratory movements, blood circulation, as well as the functional state of the central nervous system and receptor apparatus. The effectiveness of the stabilography method for assessing the coordination criteria of stability (balance) of students before and after physical exertion has been proven. The results obtained indicate that physical exercises have a positive effect on improving the indicators of students' stability (balance).

KEY WORDS: exertion, health, biomechanical analysis of statokinesiogram, physical education, stability factors, students

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INTRODUCTION

The motor activity of students at higher education institutions (HEIs) in many cases requires students' ability to hold certain working postures quite economically and with high working effect, to modify them, maintaining the balance of the body in space under different conditions of professional activities. Biomechanically rational movements and postures often determine the final result of a particular human activity and are therefore the subject of detailed research by specialists [1-3]. In the last century, the Hungarian doctor Romberg introduced the observation of the vertical position of the body into clinical practice and developed a methodology for assessing the degree of body sway and limb tremor [4]. He proved that the assessment of the vertical body position due to quantitative biomechanical criteria of stability is an important indicator of the functional state of students' bodies and their health [5].

In physical education training sessions, various static positions and postures are often used. Such static positions include various stances, hangs, and holds in gymnastic exercises, starting positions in athletics, swimming, and other sports, postures of weightlifters, shooters, etc. The role of these positions and postures as elements of sports technique can be quite different if we consider their three main phases – initial, intermediate, and final. Depending on which of these phases the static posture under study belongs to, its role in the effective solution of a motor task can be specifically assessed. The significant role of static positions and postures in sports is also evidenced by the fact that in competitions, the judicial rules regulate the fixation of static postures [7, 8].

The process of preserving the position and posture of the body is a complex process of regulation control and intermuscular coordination. From the biomechanical point of view, the human body in biostatistics can be represented as a multi-link mechanical system consisting of a number of links that do not deform. These links are connected through hinges, in which joint moments act to ensure the rigidity of the static position of the entire moving system [9]. The stabilography method is now widely used to assess the conditions of human body balance [10]. Recently, this method, in addition to studying the biomechanical foundations of stability, has also been used to study the functional state of the human body, tolerance to physical exertion of various kinds, and to assess the coordination capabilities of students in terms of their professional selection. For all the complexity of the electronic equipment used in the stabilography method, the student is not burdened with attaching sensors to the body's biological links during the measurements: they only need to stand on the stabilography platform and perform the corresponding control test. The stabilography method makes it possible to study the biomechanical characteristics of human movements, and also allows: to quantify the stability of the human body and body systems; to monitor the progress of training various types of balance in health training and sports; to test the state of students before tests; to determine adaptation to training loads; to carry out professional selection of the most capable in terms of the main quantitative indicators of stabilography [11].

Modern researches testify that the oscillation frequency of the body's Center of Mass (COM) is a key factor in the development of intermuscular coordination and the vestibular analyzer, and lies within the limits: in an ordinary person – 4-6 Hz, in athletes – 10-12 Hz, separate sports – 15-18 Hz, acrobats-quilibrists – 20-25 Hz. This means that the higher the frequency of oscillations of COM during balance exercises, the more times per unit of time the human body returns to a position of stable balance. Therefore, the probability of falling decreases and the quality of the exercise is high. Thus, the stabilography method makes it possible to quantify the stability of the human body (balance); to control the progress of training different types of balance in health training and sports; to test the condition of athletes; to study tolerance to training exertions; to carry out rehabilitation after injuries.

AIM

The aim is to investigate the biomechanical indicators of the statokinesiogram to assess coordination-related stability (balance) criteria in students before and after physical exertion.

MATERIALS AND METHODS

PARTICIPANTS

The research, which was conducted in 2024-2025, involved 30 male students of the 1st-2nd academic years of the main medical group (without health conditions) with an average level of physical development. The students studied at the Ukrainian State Dragomanov University (Kyiv, Ukraine) in the following specialties: 053 – Psychology and 014 – Secondary Education. The main criterion for including students in the study group was the absence of contraindications to physical education training sessions and informative consent to voluntary participation in the research. The students were engaged in physical education training sessions 2 times a week for 2 hours according to the current physical education program at the HEI. The physical fitness of these students did not exceed the standards of the physical education program at the HEI. There were no significant differences between health and physical fitness indicators in the studied students ($p > 0.05$).

THE SUBJECT OF THE RESEARCH

Oscillations in the body's COM, where the leading human sensory systems: vestibular, proprioceptive, and visual, integrate their contributions unequally.

RESEARCH METHODS

Analysis and generalization of literary sources (18 sources from scientometric databases MedLine, Scopus, Web of Science were analyzed), method of computerized stabilography (statokinesiometry), methods of mathematical statistics.

The method of computerized stabilography of the hardware and software complex "Force Plate with Biofeedback – Stabilan 01-2", which allows for objective registration of oscillations of the COM, as the movement of the pressure center, recorded by the sensors of the stabilization platform on which the person is located (Fig. 1) [12].

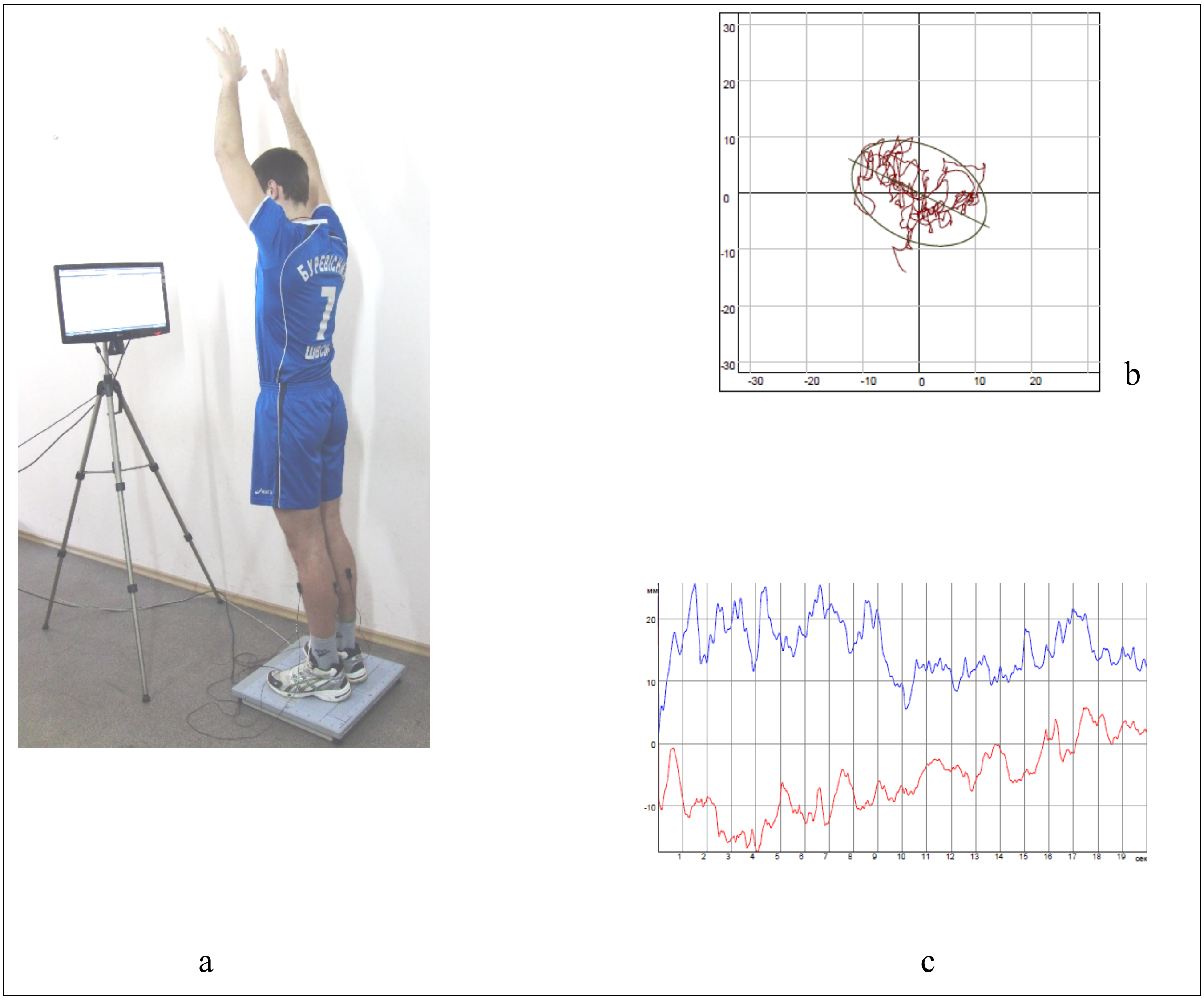

Fig. 1. Complicated Romberg stance for 20 sec (basic toe stand, feet shoulder-width apart, arms up, eyes closed) on the stabilization platform of the hardware and software complex "Force Plate with Biofeedback – Stabilan (01-2)" (a) with real-time registration on a personal computer: hodograph of stabilogram – projection of the oscillations of the COM on a horizontal plane (b); time, amplitude and frequency of oscillations of the COM in the directions: back and forth, right and left (c)
Picture taken by the authors

The hardware and software complex "Statokinesiometer – Stabilan (01-2)" was used for its intended purpose: to study the function of balance and statokinetic stability of a person by computer stabilography (statokinesiometry). It is known that during the arbitrary maintenance of an upright posture, the so-called "mobile balance" is constantly carried out. Its essence lies in the continuous redistribution of muscle tone in the main groups of antigravity muscles, aimed at stabilizing the position of the human body in space and, in particular, such resulting parameters as the center of mass and the center of gravity. The advantages of computerized stabilography include:

• comfort of the examination, which is carried out on a special stabilization platform in clothes and shoes in an upright position or sitting, i.e., in comfortable conditions that do not require special preparation of the patient or attachment of sensors to them;

• short examination time, consisting of the time of information acquisition (usually within 20-60 seconds) and the time of viewing the obtained data and analyzing the processing results, which in case of mass examinations does not exceed 1-2 minutes; informative study, which allows to assess both the general condition of a person and the state of several physiological systems involved in the process of maintaining an upright posture;

• high sensitivity to the impact on a person, which allows for to objectively assess their reaction to physical and mental influences, to taking medications, and even odors;

• multifunctionality, which allows using stabilography as a diagnostic tool for a wide range of diseases and pre-diseases, as a means of monitoring and objective assessment of impacts on a person, as well as a means of rehabilitation of disorders of human statokinetic function, training of coordination.

METHODS OF MATHEMATICAL STATISTICS

average values (X, σ, V, m), the sampling method (calculation of the Student's t test of consistency), correlation analysis (calculation of paired and multiple correlation coefficients: $_{x/y,}$ R_{tt} – Brave-Pearson) and multiple regression analysis (P. L. Chebyshev polynomials):

$\hat{Y}=a_0+a_1X_1+a_2X_2+\ldots+a_nX_n$; $\hat{Y}=b_1X_1^2+b_2X_2^2+\ldots+b_nX_n^2$,

where: $\hat{Y}$ – partial criterion (the resultant feature is S_{EllS}, mm^2 – the area of the ellipse of COM oscillations); X_n – arithmetic averages of biomechanical variables of stability criteria (factor features); a_0 – an intercept term; a_n – linear regression coefficients; and b_n – quadratic regression coefficients. When the initial data approximating the response values are sufficiently large, a transition to higher-order regression models is made:

$\hat{Y} = a_0 + a_1 X+ a_1X^2 + \ldots+a_{n-1}X^{n-1} + a_nX^n$.

This transition is carried out until the final variance is significantly reduced. In this case, the determination of whether the final variance decreases significantly was checked by statistical criteria of difference (in this case, Pearson's χ2 test was used).

ETHICAL STANDARDS

The process of research implementation is built following the requirements of scientific ethics. The Academic Ethics Commission of the Ukrainian State Dragomanov University approved the research. Also this research followed the regulations of the World Medical Association Declaration of Helsinki – ethical principles for medical research involving human subjects. The participants were informed about the aim and tasks of the research, and they voluntarily participated in it.

RESULTS

As a result of the research, the database of the subjects included the processing of 65 biomechanical indicators to assess the coordination criteria of stability (balance) of four main groups of factors: Group I – values of traditional parameters of the amplitude-frequency characteristics of COM oscillations – 21 indicators (Nos. 1-21); Group II – integral indicators of COM oscillations – 19 indicators (Nos. 22-41), Group III – parameters of vector analysis – 19 indicators (Nos. 42-61), Group IV – indicators of bioelectrical activity of the anterior and posterior surfaces of skeletal muscles of the left and right tibia – 4 indicators (Nos. 62-65). Biomechanical indicators of coordination criteria of stability are presented below:

I. Parameters of the amplitude-frequency characteristics of COM oscillations:

1. *MO(x), mm* – displacement of COM oscillations along the frontal axis (FA).
2. *MO(y), mm* – displacement of COM oscillations along the sagittal axis (SA).
3. *Q(x), mm* – scatter of COM oscillations along the FA.
4. *Q(y), mm* – scatter of COM oscillations along the SA.
5. *R, mm* – average scatter of COM oscillations.
6. *V, mm/sec* – average velocity of the COM pressure center movement.
7. *SV, sq.mm/sec* – rate of change in the area of the statokinesiogram.
8. *Angle, deg* – average direction of COM oscillations.
9. S_{EllS}, mm^2– area of the ellipse of the COM oscillations.
10. *EllE* – compression ratio.
11. *IV* – index of velocity.
12. *MA* – motion assessment.
13. *KAss0(x), %* – coefficient of asymmetry relative to zero along the FA.
14. *KAss0(y), %* – coefficient of asymmetry relative to zero along the SA.
15. *KAssM(x), %* – coefficient of asymmetry relative to the COM displacement along the FA.
16. *KAssM(y), %* – coefficient of asymmetry relative to the COM displacement along the SA.
17. *KAssO'(x), %* – coefficient of asymmetry relative to the mode along the FA.
18. *KAssO'(y), %* – coefficient of asymmetry relative to the mode along the SA.
19. *KAssE(x), %* – coefficient of asymmetry relative to the median along the FA.
20. *KAssE(y), %* – coefficient of asymmetry relative to the median along the SA.
21. *Curv, rad/mm* – coefficient of curvature of the COM displacement.

II. Integral indicators of COM oscillations.

22. *LX, mm* – length of COM displacement trajectory along the FA.
23. *LY, mm* – length of COM displacement trajectory along the SA.
24. *LFS, 1/mm* – length of the COM displacement depending on its ellipse area.
25. *QEF, %* – quality of the equilibrium function.
26. *NAV, sq.mm./sec* – normalized area of the vectorgram.
27. *CACDM, %* – coefficient of abrupt change in the direction of motion.
28. *ALV, mm/sec* – average linear velocity.
29. *ALVV, mm/sec* – amplitude of linear velocity variation.
30. *PLVV, sec* – period of linear velocity variation.

Table 1. Quantitative data of mathematical and statistical processing of biomechanical indicators of the statokinesiograms in the performance of the complicated Romberg posture (before exertion – the upper indicator, after exertion – the lower indicator (n = 30)

No	Biomechanical indicators of the statokinesiogram	X	σ	V	m	χ2 – Pearson criterion ($χ2_{gr.}$ = 0.34)	t – Student criterion ($t_{gr.}$ = 2.01)
	MO(x), mm	8.1 8.4	1.07 1.24	13.44 14.1	0.34 0.39	0.33	0.96
	MO(y), mm	6.6 8.84	0.9 1.3	13.21 14.3	0.29 0.44	0.24	**4.64**
	Q(x), mm	11.0 9.77	1.51 1.43	13.91 14.77	0.51 0.5	0.04	**2.09**
	Q(y), mm	19.84 19.93	2.84 2.94	14.01 14.22	0.92 0.94	-0.29	0.08
	R, mm	19.32 19.22	3.32 2.75	16.53 13.45	0.86 0.79	0.17	0.38
	V, mm/sec	92.84 68.34	12.64 9.85	14.2 14.43	3.87 3.14	0.33	**5.32**
	SV, mm²/sec	572 321	83.21 45.12	15.11 14.47	26.8 14.8	0.41	**8.31**
	Angle, deg	4.41 9.94	0.58 1.47	13.26 15.17	0.19 0.48	0.18	**10.97**
	S_{Ells}, mm²	3642 4012	577 568	15.12 14.13	179 187	-0.44	1.87
	EllE	1.61 1.71	0.24 0.19	14.42 11.79	0.67 0.14	**0.43**	1.63
	IV	58.12 44.01	7.66 4.44	13.53 10.74	2.39 1.42	0.34	**5.74**
	MA	90.67 88.21	13.21 12.76	14.28 14.74	4.11 4.74	0.09	0.54
	KAss0(x), %	49.76 45.89	7.43 5.21	14.23 11.11	2.23 1.58	1.23	1.49
	KAss0(y), %	24.32 43.86	3.23 7.32	14.22 15.12	1.14 2.43	-0.43	**9.38**
	KAssM(x), %	15.11 15.22	2.33 2.09	14.58 15.43	0.87 0.84	-0.28	0.43
	KAssM(y), %	13.34 14.54	1.78 2.16	14.16 15.22	0.63 0.72	0.06	1.70
	KAssO(x), %	25.56 27.08	3.58 3.87	14.09 14.23	1.21 1.18	0.32	0.94
	KAssO(y), %	50.99 72.78	6.87 8.14	13.1 11.1	2.33 2.64	-0.07	**6.43**
	KAssE(x), %	4.26 7.76	0.56 1.09	13.93 14.01	0.23 0.43	0.34	**8.94**
	KAssE(y), %	63.32 75.58	9.84 10.83	15.54 14.11	3.09 3.38	0.16	**2.67**
	Curv, rad/mm	0.36 0.49	0.04 0.07	10.93 14.60	0.01 0.02	-0.28	**5.21**
	LX, mm	698.83 546.76	90.31 75.79	12.92 13.86	28.6 24	0.06	**4.08**
	LY, mm	1448.5 1280.3	205.9 138.15	14.21 10.79	65.1 43.7	-0.02	**2.15**
	LFS, 1/mm	0.55 0.65	0.08 0.09	14.48 13.57	0.03 0.04	0.09	**2.76**
	QEF, %	1.38 2.76	0.20 0.41	14.38 14.97	0.06 0.13	-0.05	**9.54**

Table 1. Cont.

NAV, sq.mm./sec	11.09 11.85	1.48 1.11	13.31 9.38	0.47 0.35	0.04	1.30
CACDM, %	11.05 13.53	1.22 1.96	11.09 14.46	0.39 0.62	0.06	**3.40**
ALV, mm/sec	72.29 68.59	8.57 4.00	11.85 5.84	2.71 1.27	**0.56**	1.24
ALVV, mm/sec	50.04 50.86	4.85 6.44	9.69 12.66	1.53 2.04	0.13	0.32
PLVV, sec	0.52 0.52	0.02 0.02	4.23 4.45	0.01 0.02	**0.42**	0.27
AAV, deg/sec	21.35 22.84	2.58 2.31	12.09 10.12	0.82 0.73	0.05	1.36
AAVV, deg/sec	26.10 25.53	3.28 3.11	12.56 12.17	1.04 0.98	-0.01	0.40
PAVV, sec	0.50 0.46	0.03 0.03	6.24 5.90	0.01 0.02	-0.13	**2.77**
CAAV, %	7.96 9.71	1.13 1.41	14.24 14.57	0.36 0.45	-0.36	**3.05**
ADD, rev.	5.81 5.67	0.81 0.77	13.87 13.62	0.25 0.24	-0.36	0.39
ALV_f, mm/sec	29.12 27.39	3.17 2.36	10.88 8.63	1.00 0.75	0.20	1.38
ALV_s, mm/sec	58.04 57.75	7.16 7.64	12.33 13.23	2.26 2.42	-0.14	0.09
CALV_f, %	1.91 2.04	0.28 0.30	14.66 14.49	0.09 0.08	0.08	1.04
CALV_s, %	1.09 1.16	0.15 0.17	13.88 14.76	0.05 0.06	0.31	1.03
PV, sq.mm./sec	153.58 150.76	22.94 22.42	4.94 14.87	7.25 7.09	0.12	0.28
LV/AV, mm/deg	3.45 3.33	0.44 0.48	12.69 14.53	0.14 0.15	-0.28	0.60
F1(F), Hz	0.25 0.21	0.04 0.03	4.21 14.80	0.01 0.03	-0.08	**2.89**
A1(F), mm	2.43 3.74	0.30 0.57	12.37 15.26	0.10 0.18	-0.17	**6.43**
F2(F), Hz	0.42 0.37	0.06 0.05	14.87 12.94	0.02 0.03	-0.34	1.79
A2(F), mm	2.248 3.261	0.204 0.47	9.094 14.56	0.06.15	0.15	**6.18**
F3(F), Hz	0.49 0.49	0.06 0.07	12.22 14.97	0.02 0.02	-0.43	0.16
A3(F), mm	2.176 2.24	0.257 0.24	11.8 10.72	0.08 0.09	0.14	0.57
60%Pw(F), Hz	0.97 0.91	0.13 0.13	13.28 14.91	0.04 0.04	-0.02	1.16
Pw1(F), %	14.47 16.17	2.08 1.84	14.38 11.38	0.66 0.58	0.11	1.94
Pw2(F), %	69.00 67.50	4.86 4.75	7.04 7.04	1.54 1.50	0.26	0.70
Pw3(F), %	18.13 17.50	2.67 2.42	14.75 13.81	0.85 0.76	0.16	0.56

Table 1. Cont.

F1(S), Hz	0.21 0.18	0.03 0.02	14.53 12.17	0.01 0.01	**0.52**	**2.44**
A1(S), mm	6.474 6.99	0.945 1.04	14.59 14.90	0.299 0.33	-0.13	1.15
F2(S), Hz	0.28 0.22	0.04 0.03	14.39 14.17	0.01 0.01	0.29	3.95
A2(S), mm	4.75 4.88	0.68 0.73	14.40 14.92	0.22 0.23	-0.07	0.41
F3(S), Hz	0.44 0.43	0.05 0.06	12.25 14.70	0.02 0.02	-0.12	0.24
A3(S), mm	3.75 4.02	0.44 0.45	11.60 11.16	0.14 0.14	-0.19	1.35
60%Pw(S), Hz	1.18 1.12	0.09 0.12	8.06 10.61	0.03 0.04	0.26	1.28
Pw1(S), %	13.30 15.00	0.65 2.02	4.90 13.45	0.21 0.64	-0.37	**2.54**
Pw2(S), %	64.77 61.20	6.44 2.72	9.95 4.45	2.04 0.86	0.23	1.61
Pw3(S), %	23.20 23.00	3.24 2.27	13.97 9.89	1.03 0.72	-0.16	0.16
Ampl, mV-1	0.55 0.80	0.07 0.09	12.89 11.05	0.02 0.03	-0.26	**6.88**
Ampl, mV-2	0.58 0.76	0.07 0.10	12.55 12.88	0.02 0.03	-0.54	**4.65**
Ampl, mV-3	0.59 0.93	0.08 0.11	13.84 12.26	0.03 0.04	0.04	**7.62**
Ampl, mV-4	0.30 0.65	0.04 0.09	14.34 14.62	0.01 0.03	-0.04	**10.68**
Number of significant differences					**4 (α < 1 %)**	**27 (α < 5 %)**

Legend: X – arithmetic mean, σ – standard deviation, V – coefficient of variation, and m – representativeness error
Source: compiled by the authors of this study

31. *AAV, deg/sec* – average angular velocity.
32. *AAVV, deg/s* – amplitude of angular velocity variation.
33. *PAVV, sec* – period of angular velocity variation.
34. *CAAV, %* – coefficient of asymmetry of angular velocity.
35. *AAD, rev*. – accumulated angle of displacement.
36. *ALV_f, mm/sec* – average linear velocity along the FA.
37. *ALV_s, mm/sec* – average linear velocity along the SA.
38. *CALV_f,%* – coefficient of asymmetry of linear velocity along the FA.
39. *CALV_s, %* –– coefficient of asymmetry of linear velocity along the SA.
40. *PV, sq.mm./sec* – power of the vectorgram.
41. *LV/AV, mm/deg* – ratio of linear to angular velocities.

III. Vector indicators of COM oscillations.

42. *F1(S), Hz* – frequency of the first amplitude peak on the SA spectrum.
43. *A1(S), mm* – amplitude of the first amplitude peak on the SA spectrum.
44. *F2(S), Hz* – frequency of the second amplitude peak on the SA spectrum.
45. *A2(S), mm* – amplitude of the second amplitude peak on the SA spectrum.
46. *F3(S), Hz* – frequency of the third amplitude peak on the SA spectrum.
47. *A3(S), mm* – amplitude of the third amplitude peak on the SA spectrum.
48. *F2(F), Hz* – frequency of the second peak on the FA spectrum.
49. *F1(F), Hz* – frequency of the first peak on the FA spectrum.
50. *A1(F), mm* – amplitude of the first peak on the FA spectrum.
51. *A2(F), mm* – amplitude of the second peak on the FA spectrum.
52. *F3(F), Hz* – frequency of the third peak on the FA spectrum.
53. *A3(F), mm* – amplitude of the third peak on the FA spectrum.
54. *60%Pw(F), Hz* – 60 % power level of the spectrum along the FA.
55. *Pw1(F), %* – spectral power of the first zone of the stabilogram along the FA.

56. *Pw2(F), %* – spectral power of the second zone of the stabilogram along the FA.
57. *Pw3(F), %* – spectral power of the third zone of the stabilogram along the FA.
58. *60%Pw(S), Hz* – 60 % power level of the spectrum along the SA.
59. *Pw1(S), %* – spectral power of the first zone of the stabilogram along the SA.
60. *Pw2(S), %* – spectral power of the second zone of the stabilogram along the SA.
61. *Pw3(S), %* – spectral power of the third zone of the stabilogram along the SA.

IV. Indicators of bioelectrical activity of the anterior and posterior surfaces of skeletal muscles of the left and right tibiae (average amplitude for 20 seconds)

1. *Ampl, mV-1* **–** electromyogram (EMG) of the anterior surface muscles of the left tibia.
2. *Ampl, mV-2* – EMG of the anterior surface muscles of the right tibia.
3. *Ampl, mV-3* – EMG of the posterior surface muscles of the left tibia.
4. *Ampl, mV-4* – EMG of the posterior surface muscles of the right tibia.

The results of mathematical and statistical processing of all biomechanical indicators of the statokinesiogram in the performance of the complicated Romberg posture for 20 seconds (the main stand on toes, feet on the width of shoulders, arms up) before and after exertion at physical training sessions are presented in Table 1.

The results obtained once again show that students demonstrate stable statokinesiogram indicators with a significantly unchanged ellipse area of the COM oscillations before and after exertion (S_{EllS} – 3606 and 4004 mm^2; $\alpha > 5$ %). The total number of significant differences was 27 (43 % $\alpha < 5$ %). Moreover: in Group I there were 11 (53 %): 2, 3, 6, 7, 8, 11,14, 18, 19, 20, 21; in Group II there were 7 (38 %): 22, 23, 24, 25, 27, 33, 34); in Group III there were 5 (27 %): 42, 43, 45, 52, 59; in Group IV there were 4 (99.9 %): 62, 63, 64, 65. It means that the regulation of posture in students is more effective at the expense of the economy of changes of indicators of the body's COM statokinesiogram in Groups I, II, and III, and also a 99 % increase of all indicators in Group IV.

The analysis of correlations shows 57 % of reliable correlation relationships before and 43 % after exertion, that is, the process of stability control from the phase of irradiation passed into the phases of concentration and stabilization. More correlation relationships decreased in Group I (18 from 21 – 88 %) and Group II of indicators (16 from 19 – 84 %).

The further regression analysis was carried out as follows: the main factor of quality of maintenance of balance in a given posture – S_{EllS} – area of ellipse of the COM oscillations – was taken as a partial criterion (resultant feature $\hat{Y}$); biomechanical indicators of statokinesiograms having reliable correlation relationships with S_{EllS}, 13 indicators before exertion (these are nos. 1–12, 13, 14, 16. 17, 20, 31, 36, 38, 44, 52, 54, 60 of the Table) and 9 after exertion (these are nos. 1–2, 4, 7, 12, 13, 14, 21, 35, 44 of the Table) were taken as factors features.

The results of the regression analysis indicate that the indicators make the greatest contribution to the resultant feature $\hat{Y}$ (S_{EllS}) of the stability margin assessment: 12. MA – motion assessment; 13. KAss0(x), % – coefficient of asymmetry relative to zero along the frontal axis; 16. KAssM(y), % – coefficient of asymmetry relative to the COM displacement along the sagittal axis.

The indicators of the stability margin assessment allowed us to evaluate the possibility of body deviation forward, backward, right, and left. According to the asymmetry of the resulting zone, one can speculate about hidden disorders of posture regulation and their predominance in any direction.

DISCUSSION

Scientists [13, 14] note that biolinks are a kind of lever and pendulum. Bones that are connected in a movable way form the basis of biokinematic pairs and biochains. The forces applied to them (muscle traction and others) act on the links of biokinematic chains like levers. This makes it possible to transmit the effect of the force through the links at a distance, as well as to change the effect of the applied forces. Bone levers, which are movably connected in joints, can maintain their position and change it under the influence of applied forces. All forces applied to a bone link as a lever can be divided into groups: 1) forces that lie in the plane of the joint axis (they cannot affect the movement around this axis); 2) forces that have components that lie in the plane perpendicular to the axis of the lever (these forces can affect the movement around this axis in two directly opposite directions), i.e. moving (directed behind the movement) and inhibitory (directed opposite to the movement).

The optimal functioning of the vestibular sensory system is of practical importance for achieving the planned sports results in various sports, but, most of all, in those where the athlete is required to demonstrate a high level of sensorimotor coordination. Development and improvement of sensorimotor coordination as a basis of technical fitness are achieved through vestibular training (orientation, coordination, body posture, balance, motor interaction) with strict regulation and control of the exercises performed. The lack of adequate training of the vestibular analyzer causes a violation of sensorimotor coordination, which, in turn, leads to technical errors in the movements of athletes [15, 16].

The laws of classical physics are applied in the human musculoskeletal system, namely, they allow us to consider in more detail the possibilities of the motor function of the human body: restoration of lost movements through the construction of special motor programs in physical education and sports rehabilitation and health training of a person, taking into account the characteristics of each individual; development of motor skills, including strength, as the main criterion for the ability to work with the human body's supporting-motor apparatus in conditions of constant, overcoming mechanical work. An example can be simulators with a special design, where overcoming work is always performed in rotational movements, such as a biceps machine with an eccentric [17].

Our research shows that when controlling balance, the human body does not always obey the laws of mechanics: in Fig. 1 b, the hodograph of the stabilogram – the projection of the COM oscillations on the horizontal plane goes beyond the support area, but the balance is maintained, which is confirmed by the research of many experts [2, 5, 9, 17, 18].

CONCLUSIONS

1. The reason for oscillations of the center of gravity is respiratory movements, blood circulation, as well as the functional state of the central nervous system and the receptor apparatus controlling the motor muscular system, which causes the opposite effects of various somatic and nervous disorders, intoxication and fatigue on the student's balance system. Considering the above, as well as the simplicity of registration of stabilographic indicators, the possibility of obtaining them without distracting the student from the activity performed and the high sensitivity of this method, it is possible to use stabilography as a convenient method for assessing the dynamics of the functional state of students in the conditions of physical exertion, functional disorders of the central nervous system and musculoskeletal system.
2. The leading role of proprioceptive, amplitude-frequency characteristics of the body's COM oscillations in balance control has been proven. The results indicate that the greatest contribution to the resultant feature $\hat{Y}$ *(S_{Ells} ellipse area of the COM oscillations)* is made by the indicators of stability margin assessment: 12. *MA* – motion assessment; 13. *KAss0(x), %* – coefficient of asymmetry relative to zero along the frontal axis; 16. *KAssM(y), %* – coefficient of asymmetry relative to the COM displacement along the sagittal axis.
3. The student's keeping of balance is a dynamic phenomenon requiring continuous body movement. It is the result of the interaction of vestibular and visual analyzers, joint and muscle proprioception, central and peripheral nervous systems.
4. Students demonstrate stable indicators of statokinesiogram with a significantly unchanged area of the ellipse of the COM oscillations before and after exertion (S_{Ells} – 3606 and 4004 mm^2; $\alpha > 5$ %). The total number of significant differences was 27 (43 % $\alpha < 5$ %). Moreover: in Group I there were 11 of them (53 %): 2, 3, 6, 7, 8, 11,14, 18, 19, 20, 21; in Group II there were 7 (38 %): 22, 23, 24, 25, 27, 33, 34); in Group III there were 5 (27 %): 42, 43, 45, 52, 59; in Group IV there were 4 (99.9 %): 62, 63, 64, 65. These indicators characterize the increase in muscle tone and improvement of body posture. The obtained results indicate that physical exercises have a positive effect on improving students' stability (balance).
5. The analysis of correlations shows 57 % of reliable correlation relationships before and 43 % after exertion, that is, the process of stability management from the phase of irradiation passed into the phases of concentration and stabilization. More correlation relationships decreased in the first (18 out of 21 – 88 %) and second groups of indicators (16 out of 19 – 84 %). Thus, it has been proven that the stabilographic method provides an important positive qualitative and quantitative assessment of the body's response to physical exertion.

PROSPECTS FOR FURTHER RESEARCH

Prospects for further research are seen in the study of biomechanical indicators of stability (balance) of students (male and female) in the process of practicing various sports.

REFERENCES

1. Onursal Kılınç Ö, De Ridder R, Kılınç M, Van Bladel A. Trunk and lower extremity biomechanics during sit-to-stand after stroke: A systematic review. Ann Phys Rehabil Med. 2023;66(3):101676. doi:10.1016/j.rehab.2022.101676. DOI
2. Hoareau D, Fan X, Abtahi F, Yang L. Evaluation of In-Cloth versus On-Skin Sensors for Measuring Trunk and Upper Arm Postures and Movements. Sensors (Basel). 2023;23(8):3969. doi:10.3390/s23083969. DOI
3. Turner M, Hammer N, Lamping E et al. Kinetics, Kinematics, and Fixed Postures: An Exploration of How Attentional Focus Manipulation Enhances Movement. Res Q Exerc Sport. 2023;94(1):246-253. doi:10.1080/02701367.2021.1965522. DOI
4. Forbes J, Munakomi S, Cronovich HA. Romberg Test. In: StatPearls. Treasure Island (FL). 2023.
5. Halmágyi GM, Curthoys IS. Vestibular contributions to the Romberg test: Testing semicircular canal and otolith function. Eur J Neurol. 2021;28(9):3211-3219. doi:10.1111/ene.14942. DOI
6. Wong TKK, Ma AWW, Liu KPY et al. Balance control, agility, eye-hand coordination, and sport performance of amateur badminton players: A cross-sectional study. Medicine (Baltimore). 2019;98(2):e14134. doi:10.1097/MD.0000000000014134. DOI
7. Donatelli R, Wooden M, Ekedahl SR et al. Relationship between static and dynamic foot postures in professional baseball players. J Orthop Sports Phys Ther. 1999;29(6):316-330. doi:10.2519/jospt.1999.29.6.316. DOI
8. Akinoğlu B, Paköz B, Shehu SU et al. Evaluation of Athletes' Gender-Related Postural Differences. Percept Mot Skills. 2025;132(3):534-547. doi:10.1177/00315125241304809. DOI
9. Gómez-Landero LA, Leal Del Ojo P, Walker C, Floría P. Static balance performance differs depending on the test, age and specific role played in acrobatic gymnastics. Gait Posture. 2021;90:48-54. doi:10.1016/j.gaitpost.2021.07.023. DOI
10. Slota GP, Granata KP, Madigan ML. Effects of seated whole-body vibration on postural control of the trunk during unstable seated balance. Clin Biomech (Bristol). 2008;23(4):381-386. doi:10.1016/j.clinbiomech.2007.11.006. DOI
11. Ostrowska B, Rozek-Piechura K, Skolimowski T. Recovery of dynamic balance following external posture disturbance in children with idiopathic scoliosis. Ortop Traumatol Rehabil. 2006;8(3):300-307.
12. Kamahina RS, Nazarenko AS, Shamsuvaleeva ES, Nizamova CI. Balance function control on the background of vestibular stimulation in athletes. International Journal of Green Pharmacy. 2018;12(2):S363-S367.
13. Vandenberghe A, Vannuscorps G. Predictive extrapolation of observed body movements is tuned by knowledge of the body biomechanics. J Exp Psychol Hum Percept Perform. 2023;49(2):188-196. doi:10.1037/xhp0001077. DOI
14. Swinton PA, Lloyd R, Keogh JW et al. A biomechanical comparison of the traditional squat, powerlifting squat, and box squat. J Strength Cond Res. 2012;26(7):1805-1816. doi:10.1519/JSC.0b013e3182577067. DOI
15. Saunders PU, Pyne DB, Telford RD, Hawley JA. Factors affecting running economy in trained distance runners. Sports Med. 2004;34(7):465-485. doi:10.2165/00007256-200434070-00005. DOI
16. Dos'Santos T, Thomas C, Comfort P, Jones PA. The Effect of Training Interventions on Change of Direction Biomechanics Associated with Increased Anterior Cruciate Ligament Loading: A Scoping Review. Sports Med. 2019;49(12):1837-1859. doi:10.1007/s40279-019-01171-0. DOI
17. Nuzzo JL, Pinto MD, Nosaka K. Muscle strength and activity in men and women performing maximal effort biceps curl exercise on a new machine that automates eccentric overload and drop setting. Eur J Appl Physiol. 2023;123(6):1381-1396. doi:10.1007/s00421-023-05157-9. DOI
18. Yeadon MR, Pain MTG. Fifty years of performance-related sports biomechanics research. J Biomech. 2023;155:111666. doi:10.1016/j.jbiomech.2023.111666. DOI

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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