

# The Influence of Lower Limbs Strength Training on the Postural Stability of Physically Active Girls

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Received January 12, 2022; revised May 12, 2022; accepted May 27, 2022

**Abstract**—The aim of this work was to study the influence of strength training on postural stability of young physically active girls ( $n = 38$ , 17–21 years old). Half of the girls ( $n = 19$ ) trained the strength abilities of the lower limbs for 10 weeks (3 times a week) and the other half of the girls ( $n = 19$ ) made up the “Control.” To assess the one-leg posture stability, fluctuations of the center of pressure (COP) and fluctuations of the angles in the ankle and knee joints were determined in the tests: (1) on a stabiloplatfrom with eyes open (EO) and eyes closed (EC); (2) on a low see-saw ( $h = 10$  cm) with EO and EC; and (3) on a high ( $h = 30$  cm) see-saw with EC. Strength abilities were recorded using functional tests. The composition of the whole body and lower limbs was determined using bioimpedance analysis. Compared with the “Control” group, the trained girls showed an increase of strength abilities without signs of muscle hypertrophy, as well as a tendency ( $p < 0.09$ ) to an increased stability of the knee joint in standing on a low see-saw. The accuracy of the reproduction of the vertical body inclination did not change after training. However, decreases of fluctuations in COP and angles in the ankle joint during stance on the stabiloplatfrom and on the low see-saw, as well as an increase in the balance time on the high see-saw, revealed after strength training, did not differ from the changes in these indices in “Control.” Thus, despite the increased stability of the knee joint, strength training of the leg muscles has practically no effect on the regulation of static (on the solid support) and semi-dynamic (on the movable see-saw) postural balance.

**Keywords:** postural stability, stabilography, static and semi-dynamic balance, strength training, one-leg posture, see-saw

**DOI:** 10.1134/S0362119722700062

## INTRODUCTION

Many studies have shown an increased static stability of the vertical posture in athletes involved in various types of training: shooters, various players, gymnasts, wrestlers, skiers, and others [1, 2]. However, the mechanisms underlying the increased postural ability of most athletes have not yet been fully elucidated.

The postural regulation system is a complex multi-level system including the central control apparatus, sensory systems, and the executive neuromuscular apparatus [3]. Sports training affects all these components and leads to an increase in its effectiveness. One hypothesis suggests that posture regulation improves with the development of the strength abilities of the postural muscles. Indeed, an increased rate and amplitude of fluctuations of the center of pressure (COP) of the body have been established in elderly persons with age-related sarcopenia [4, 5] or at decreased strength abilities in polio patients [6]. Con-

versely, in weightlifters, the posture stability, especially in the absence of visual information and (on a compliant) support, is significantly higher than in young subjects who do not go in for sports [7], indicating a possible influence of strength abilities on the posture balance. An increase in the strength of the postural muscles will reduce the tension of the central apparatus of the posture regulation system (i.e., the activity of nervous processes to generate the necessary muscle strength), which is manifested in an increase in the posture stability. For example, an increase in the speed of COP fluctuations is combined with greater relative values of electromyographic activity and torque of the calf muscles during postural tests [4].

However, the results of experimental studies of the effect of strength training are contradictory. Some studies showed the effectiveness of strength training (e.g., in elderly subjects with initially low strength abilities) [5]. The mechanisms mediating the effect of strength training may be associated with an increase in

the rate of development of muscle tension and timely postural corrections [8], a decrease in the strain of the central component of posture regulation and automation of the control process [4], as well as with an increase in proprioceptive sensitivity and, hence, the accuracy of postural corrections [6].

However, other studies, performed on young subjects, showed no positive changes in the regulation of static posture under the influence of strength training [9].

The purpose of this study was to assess the effectiveness of strength training of the muscles of the lower limbs, which ensure postural function, in improving the static and semi-dynamic posture stability in young physically active girls.

## MATERIALS AND METHODS

*Organization of the study.* The study involved apparently healthy female volunteer students ( $n = 38$ , 18–21 years old) without diseases of the central and peripheral neuromuscular system and organs of vision, who led a physically active lifestyle. Half of the girls ( $n = 19$ ) were included in the “Control” group, and the other half ( $n = 19$ ) formed the experimental group “Strength.”

All parameters were evaluated before and after a 10-week strength training program. The control group led a habitual way of life and performed physical exercises within the “physical culture” discipline of the university (twice a week). The experimental group trained according to the program of speed-strength training for the muscles of the lower limbs (3 times a week for 60–80 min). Each training session included 15-min general warm-up (running and jumping exercises and warm-up exercises for the joints of the legs and torso); plyometric exercises (15–20 min, jumps from the gymnastic bench, jumps to the bench with jumping up, and jumps up and in length from one and two legs using additional weights of 3–5–7 kg); exercises with a barbell and dumbbells (15–20 min, squatting with a barbell, lunges with dumbbells, the 10–30 repetition maximum (RM) (that is, the weight of the sports equipment the maximum number of repetitions with which is 10–30); exercises on strength-simulators (15–20 min, flexion and extension of the legs in the knee joint with resistance of 5–20 RM); and general developmental exercises (5 min). The exercises were performed by the repeated strength training method. The rest interval between sets varied from 1 min after low-intensity exercises to 3–4 min after near-maximal resistance.

*Body composition assessment* was performed with an ABC-01 bioimpedance analyzer and ABC-01-0454 polysegment analysis program (Medass, Moscow). The body length and weight were measured with medical scales and a stadiometer. Bioimpedance measurements were performed in supine position on the 10th–

12th min with current and measuring electrodes placed on both wrists and both ankles. In the ABC-01-0454 program, the following indices were calculated: fat (FM in kg) and fat-free (FFM in kg) mass of the whole body and lower limbs. For the analysis, the average value of FM and FFM for both limbs was used.

*Static stability of vertical posture* was determined on a solid and immobile stabiloplatfrom (Neurocor Trast-M, Russia; signal sampling frequency 500 Hz) by assessing COP fluctuations in a one-leg stance on the non-dominant limb with eyes open (EO, 40 s) and eyes closed (EC, 40 s), with the second leg bent at the knee joint (about 100 deg) and the arms crossed and pressed to the chest. In the EO position, the subjects fixed their gaze on a circle (radius 10 cm) located at a distance of 2 m from the platform.

*Semi-dynamic stability of one-leg posture* was determined in two tests on see-saws of different heights movable in the sagittal plane: (1) low ( $h = 10$  cm) and (2) high ( $h = 30$  cm). Semi-dynamic balance means the ability to maintain the COP within the support base movable (swinging) about any axis [9]. The low see-saw ( $h = 10$  cm,  $r = 60$  cm) placed on a stabiloplatfrom was used to record COP fluctuations in a one-leg stance with eyes open (40 s) and eyes closed (40 s). The high see-saw ( $h = 30$  cm,  $r = 60$  cm) was used only to determine the average time (s) of standing in a one-leg stance with eyes closed in three attempts. The high see-saw served to determine the maximum ability for postural balance on one leg. An ordinary young girl could stand on this see-saw for about 10 s before the loss of balance.

To analyze the postural stability on the stabiloplatfrom and on the low see-saw, we used the following indices: (1) the average linear speed of the COP ( $V$ -COP, mm/s) and (2) 95% area of fluctuations of the COP ( $S$ -COP, mm<sup>2</sup>).

*Kinematic analysis of the one-leg posture.* During postural tests on the stabiloplatfrom (and on the low see-saw), angle fluctuations in the knee (KJ) and ankle (AJ) joints of the supporting limb were determined simultaneously with the COP using three gyroscope sensors (Neurocor Trast-M), which were fixed with an elastic tape on the back of the foot and on the lateral sides of the lower leg and thigh. For the analysis, we used the indices of angle fluctuations in the KJ and AJ of the supporting limb in the sagittal (s) and frontal (f) plane: (1) standard deviation (or amplitude) ( $SDs/f$ -AJ and  $SDs$ -KJ in deg) and (2) average angular velocity of fluctuations ( $Vs/f$ -AJ and  $Vs$ -KJ in deg/s).

*Specific (or postural) proprioceptive sensitivity* was defined as the ability to actively reproduce the angle of inclination with a straight body in the ankle joint. The test included several stages: (1) 10-s vertical two-leg stance with EC on a stabiloplatfrom; (2) inclination with a straight body (with arms pressed on the sides to the body) by bending forward in the AJ until the chest

touches the limiter located at a distance of 5 cm from the chest (2–3 s); (3) memorization for 5 s of a static vertical posture bent in the AJ with EC (working posture); (4) return to the initial vertical position with EC while maintaining the vertical posture for 5 s; and (5) independent reproduction of the working posture at the command of the experimenter for 5 s with a return to the initial vertical position. Reproduction of a tilt with a straight body performed three times. To assess the specific proprioceptive sensitivity, we determined the following indices: the absolute average (for three attempts) error in reproduction of the COP deviation (in mm) and the absolute average error in reproduction of the angle in the ankle (AJ) and hip (HJ) joints (in mm deg). The effectiveness of this technique was tested by us earlier [10].

*Strength abilities* were determined using the following functional tests: (1) standing long jump (in cm); (2) 12-m running time with automatic time logging using Apple iPad and the SprinterTimer app; (3) strength tests—flexion (maximum number of repetitions with a weight of 30 kg) and extension (maximum number of repetitions with a weight of 40 kg) of both legs in the knee joint on a special strength simulator.

*Statistics.* The results are presented in the tables as the median (*Me*)  $\pm$  interquartile range (25–75%). Two-way analysis for variance (ANOVA) for repeated measurements was used to determine the differences in the dynamics of the body composition and strength ability indices between the “Control” and “Strength” groups. For all indices, the degree of change over the experimental period relative to the initial level ( $\Delta$ , %) was determined. According to the Shapiro–Wilk test, many indices had an abnormal distribution. Comparative analysis between groups was performed using the Mann–Whitney test. Differences before and after the experimental period in the groups were estimated using the Wilcoxon paired test. Correlation analysis was performed for changes in indices over the experimental period ( $\Delta$ ) using the Spearman rank correlation (*r*). The differences in the number of subjects who completed the “Stance on the low see-saw with EC” test between the groups before training were analyzed using the Chi-square ( $\chi^2$ ) test, and the differences in the number of subjects who completed this test before and after training within the groups were assessed by the McNemar’s test. Calculations were performed using the Statistica v12 software.

## RESULTS

*Changes in the body composition under the influence of 10-week strength training.* The groups did not differ in terms of the body composition parameters (body mass and length, fat-free mass (FFM) of the body, fat mass (FM) of the body, as well as FFM and FM of the lower limbs in kg) both before and after training. However, during the training period, the body mass in the

“Strength” group increased ( $+0.6 \pm 1.1$  kg,  $p = 0.026$ ) compared with the initial level and  $-0.4 \pm 1.1$  kg,  $p > 0.05$  compared with the initial level in the “Control” group,  $p = 0.008$  between groups), mainly due to the FFM of the body (Fig. 1a), and the change in the FFM of the body in the “Strength” group was nonsignificant (Fig. 1b). Thus, in the “Strength” group, a slight anabolic effect at the whole body level was detected.

Despite the training, we revealed no significant changes in the FFM (Fig. 1c) and FM (Fig. 1d) of the lower limbs in kg in relation to the initial level. In addition, no significant differences between the groups in changes ( $\Delta$ ) of the FFM and FM of the lower limbs during the observation period were found. Thus, we did not record any hypertrophy of the trained muscles of the lower limbs by bioimpedancemetry after training, despite the slight positive shift in the FFM of the whole body in the “Strength” group.

*Strength abilities of the lower limbs.* Before training, the groups did not differ in the strength indices. After the 10-week training, the “Strength” group showed a significant improvement in all strength tests as compared to the “Control” group (in all functional tests,  $p < 0.05$  according to ANOVA, Fig. 2).

As a result, after the 10-week training, the indices of the girls in the “Strength” group in the tests “extension and flexion of the legs at the knee joints” became significantly higher ( $p < 0.05$ , Figs. 2c, 2d), and the indices in the long jump increased on a trend level ( $p = 0.063$ , Fig. 2b) compared to those in the “Control” group.

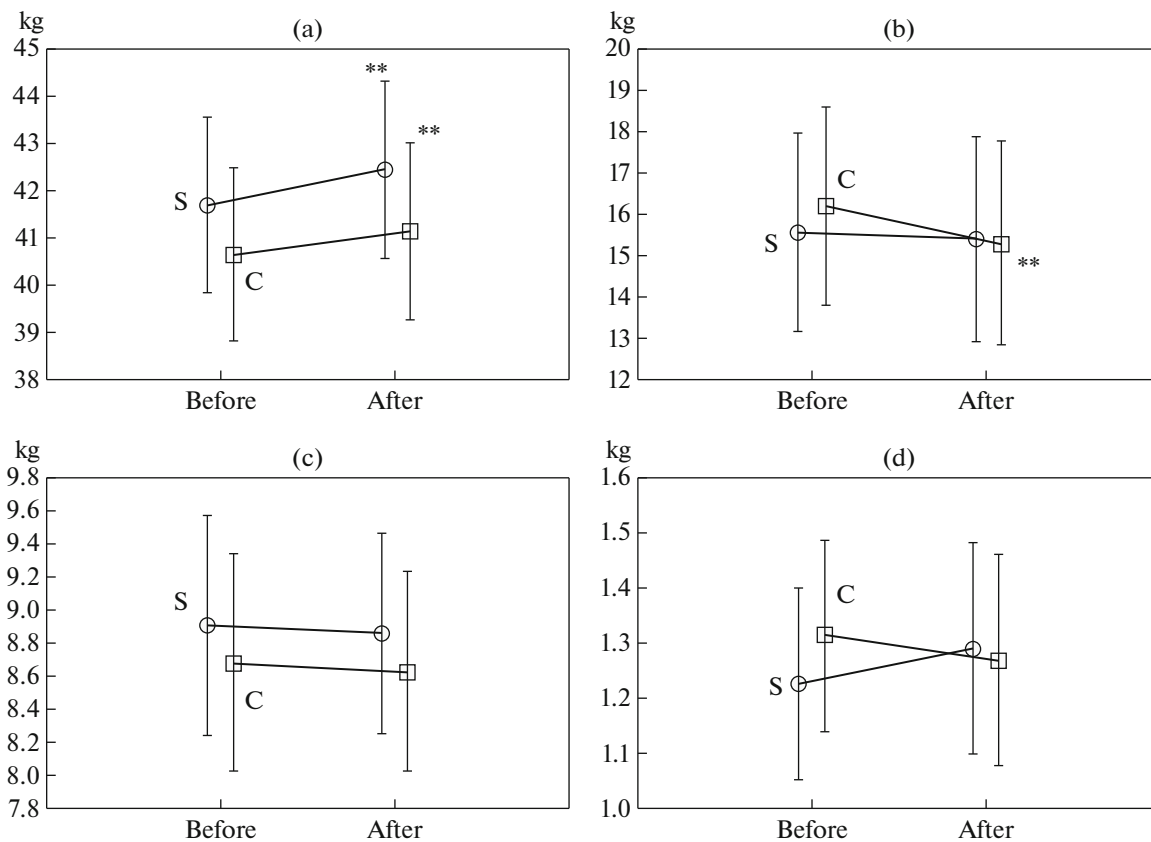
### *Static Postural Stability after Strength Training*

#### *One-leg stance on a stabiloplatfrom with eyes open.*

The groups did not differ in any indices of fluctuations in the COP, knee and ankle joints in the one-leg stance both before and after the strength training (Table 1). In addition, despite the decrease in  $V$ -COP ( $p < 0.05$ ),  $V_s$ -KJ ( $p < 0.1$ ),  $SDF$ -AJ ( $p < 0.05$ ), and  $Vf$ -AJ ( $p < 0.01$ ) after the training in the “Strength” group, no differences from the changes in these indices in the “Control” group were found.

The changes in the stabilographic and kinematic indices in the stance on the platform with EO did not correlate with the changes in the composition of the body or lower limbs ( $p > 0.1$  in all cases). Of all the strength indices, only the increase in the leg extension at the knee significantly correlated with  $\Delta V_s$ -AJ-EO on the platform ( $r = -0.33$ ,  $p = 0.042$ ). Slight correlations were also found between the increase in the length of the jump with (1)  $\Delta SDF$ -AJ-EO ( $r = -0.30$ ,  $p = 0.067$ ) and (2)  $\Delta Vf$ -AJ-EO ( $r = -0.31$ ,  $p = 0.052$ ).

*One-leg stance on a platform with eyes closed.* The groups did not differ in either stabilographic or kinematic indices of the stability of the one-leg posture in the stance with EC both before and after training



**Fig. 1.** Changes in the body composition in the “Strength” (S) and “Control” (C) groups after 10 weeks of strength training ( $M \pm 95\%$  CI). (a) Fat-free mass (FFM, kg) of the body (ANOVA,  $p = 0.270$ ), (b) fat mass (FM, kg) of the body (ANOVA,  $p = 0.031$ ), (c) FFM of the limbs (kg) (ANOVA,  $p = 0.976$ ), (d) FM of the limbs (kg) (ANOVA,  $p = 0.340$ ). \*\*  $p < 0.01$ , Significance of differences compared to the initial level before training, calculated by the post hoc test of the least significant difference. ANOVA,  $p$ —differences in the dynamics of indices during the training period between groups C and S.

(Table 2). After the strength training, the following indices in the “Strength” group decreased compared with the initial level (Table 2):  $V_s$ -KJ-EC ( $p < 0.05$ ),  $SDf$ -AJ-EC ( $p < 0.01$ ), and  $Vf$ -AJ-EC ( $p < 0.01$ ), as well as the amplitude (SD) of COP fluctuations in the frontal plane ( $-5.54 \pm 22.2\%$ ,  $p = 0.018$ , data not shown). However, these changes in the “Strength” group did not differ from the changes in these indices in the “Control” group (Table 2).

The changes in the stabilographic and kinematic parameters in the stance on the platform with EC did not correlate with the changes in the composition of the body and lower limbs ( $p > 0.1$  in all cases). Of the functional tests, only the increase in the result in the standing long jump test weakly correlated with  $\Delta SDf$ -AJ-Pl-EC ( $r = -0.38$ ,  $p = 0.018$ ).

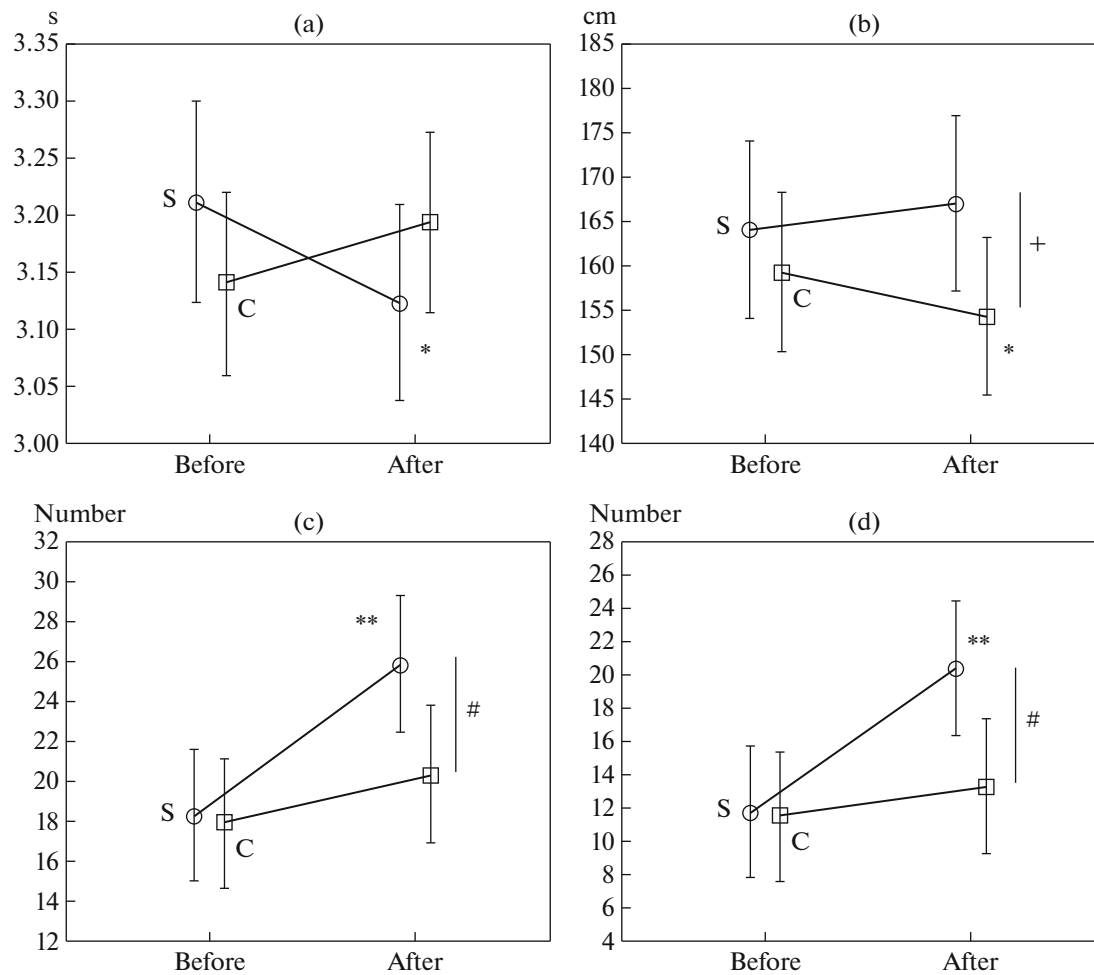
#### Semi-Dynamic Postural Stability after Strength Training

*One-leg stance on a low see-saw with eyes open.* The groups did not differ both before and after strength training in practically all indices (except the increased  $V$ -KJ-s before training in the “Strength” group)

(Table 3). The greatest differences at the trend level in the dynamics of indices between the groups were noted for the knee joint: the amplitude ( $\Delta SD$ -KJ-s,  $p = 0.098$ ) and speed ( $\Delta V$ -KJ-s,  $p = 0.062$ ) of fluctuations in the knee joint after training in the “Strength” group decreased slightly greater than in the “Control” group. However, changes in other indices recorded during the training period did not differ between the groups.

The increase in FFM of the body weakly correlated with  $\Delta SD_s$ -KJ-SS-EO ( $r = -0.31$ ,  $p = 0.048$ ); no correlations with changes in the FM and FFM of the legs were found ( $p > 0.1$  in all cases). In terms of the strength indices, only the increase in the number of leg extensions in the knee correlated with a decrease in (1)  $SDf$ -AJ-SS-EO ( $r = -0.34$ ,  $p = 0.030$ ) and (2)  $Vf$ -AJ-SS-EO ( $r = -0.29$ ,  $p = 0.074$ ).

*One-leg stance on the low see-saw with eyes closed.* The test on the low see-saw (to stand for 40 s) was a fairly difficult postural task. Before the training, the test was not completed by 47% (9 of 19) of the girls in the “Strength” group and by 33% (7 of 21) of the girls in the “Control” group ( $p = 0.5$  between the



**Fig. 2.** Changes in the strength indices in the groups “Strength” (S) and “Control” (C) after 10 weeks of strength training ( $M \pm 95\%$  CI). (a) 12 m running time (ANOVA,  $p = 0.003$ ), (b) standing long jump (ANOVA,  $p = 0.018$ ), (c) extensions of the leg in the knee on a simulator with a resistance of 40 kg (ANOVA,  $p = 0.024$ ), (d) flexions of the legs in the knee on a simulator with a resistance of 30 kg (ANOVA,  $p = 0.001$ ). \*/\*\*  $p < 0.05/0.01$  Significance of differences compared to pre-training baseline calculated by post hoc test of least significant difference. ANOVA,  $p$ —differences in the dynamics of indices during the training period between groups C and S. +/#— $p < 0.1/0.05$  between groups C and S after training.

“Strength” and “Control” groups according to the  $\chi^2$  test). After the training, the test was not completed by 16% of the girls in the “Strength” group (3 of 19,  $p < 0.09$  according to the McNemar test between before and after) and by 29% of the girls in the “Control” group (6 of 21,  $p = 0.81$  according to the test McNemar between before and after). The difference between the groups in the number of subjects who completed this test was nonsignificant.

Stabilometric analysis was performed on 10 girls of the “Strength” group and 11 girls from the “Control” group who passed the test completely before and after the training program. In the “Strength” group, a decrease in the following indices was revealed after training:  $S$ -COP-SS-EC by 27.2% at a level of a trend ( $p = 0.06$ ),  $V$ -KJ-SS-EC by 20.0% ( $p < 0.05$ ),  $SDf$ -AJ-SS-EC by 22.8% ( $p < 0.05$ ), and  $Vf$ -AJ-SS-EC by 20.1% ( $p < 0.05$ ) compared with the initial values

(Table 4). However, the differences in  $\Delta SD$ -KJ-SS-EC ( $p = 0.079$ ) and  $\Delta V$ -KJ-SS-EC ( $p = 0.079$ ) between the “Strength” and “Control” groups were at a trend level (Table 4).

Correlation analysis was performed for the participants who completed the test before and after training ( $n = 21$ ). A significant correlation was found only between the indices  $\Delta SD$ s-KJ-SS-EC and  $\Delta 12$ -m running time ( $r = 0.46$ ,  $p = 0.038$ ).

*One-leg stance on the high see-saw with eyes closed.* The groups did not differ in the time of retaining the one-leg stance on the high see-saw both before and after the 10-week strength training (Fig. 3). After the course of training, the balance time in the “Strength” group increased statistically significantly, though only by 3.8 s ( $p = 0.040$  compared to the initial level). However, this increase did not differ from the change in the

**Table 1.** Stabilographic and kinematic indices of postural stability on a stabiloplatform with eyes open, *Me* [25–75%]

Indices	“Strength”	“Control”	<i>p</i>
Center of pressure			
<i>V</i> -COP-EO, mm/s (before)	32.3 [26.9–36.7]	30.6 [26.3–35.6]	0.274
<i>V</i> -COP-EO, mm/s (after)	29.8 [24.3–36.9]	26.0 [22.3–33.5]	0.255
$\Delta V$ -COP-EO, %	–11.2 [–18.6–2.0]*	–14.7 [–19.1–5.0]**	0.381
<i>S</i> -COP-EO, mm <sup>2</sup> (before)	328 [223–433]	312 [214–397]	0.231
<i>S</i> -COP-EO, mm <sup>2</sup> (after)	265 [227–307]	245.0 [181–349]	0.599
$\Delta S$ -COP-EO, %	–14.1 [–47.6–18.8]	1.0 [–25.0–21.4]	0.231
Knee joint			
<i>SDs</i> -KJ-EO, deg (before)	0.75 [0.43–1.21]	0.65 [0.48–0.99]	0.672
<i>SDs</i> -KJ-EO, deg (after)	0.55 [0.31–0.94]	0.61 [0.42–0.89]	0.530
$\Delta SDs$ -KJ-EO, %	–19.64 [–53.38–44.62]	9.07 [–53.75–44.62]^	0.804
<i>Vs</i> -KJ-EO, deg/s (before)	2.08 [1.34–3.03]	1.96 [1.61–2.67]	0.530
<i>Vs</i> -KJ-EO, deg/s (after)	2.09 [1.53–2.98]	1.81 [1.41–2.85]	0.726
$\Delta Vs$ -KJ-EO, %	–5.22 [–21.74–8.60]*	–10.21 [–24.36–12.46]	0.884
Ankle joint			
<i>SDs</i> -AJ-EO, deg (before)	0.73 [0.61–0.97]	0.69 [0.55–1.77]	0.521
<i>SDs</i> -AJ-EO, deg (after)	0.74 [0.57–1.14]	0.75 [0.61–1.15]	0.815
$\Delta SDs$ -AJ-EO, %	–9.86 [–26.97–13.85]	3.41 [–30.43–53.45]	0.365
<i>Sdf</i> -AJ-EO, deg (before)	1.47 [0.92–2.83]	1.65 [1.15–2.34]	0.683
<i>Sdf</i> -AJ-EO, deg (after)	1.15 [0.74–2.08]	1.55 [0.91–1.98]	0.793
$\Delta Sdf$ -AJ-EO, %	–26.32 [–40.14–3.48]**	–2.99 [–33.76–13.98]	0.381
<i>Vf</i> -AJ-EO, deg/s (before)	6.69 [3.89–9.84]	5.54 [4.26–9.41]	0.726
<i>Vf</i> -AJ-EO, deg/s (after)	4.67 [3.31–7.70]	5.19 [3.48–7.64]	0.849
$\Delta Vf$ -AJ-EO, %	–26.93 [–37.12–2.31]**	–19.21 [–27.09–3.86]*	0.579
<i>Vs</i> -AJ-EO, deg/s (before)	2.28 [1.85–3.27]	2.07 [1.80–2.69]	0.231
<i>Vs</i> -AJ-EO, deg/s (after)	2.61 [1.98–3.23]	2.28 [1.75–2.86]	0.465
$\Delta Vs$ -AJ-EO, %	2.54 [–20.18–24.89]	–4.58 [–12.72–35.51]	0.484

*V*-COP is the rate of fluctuations in the COP,  $\Delta$  is the change during the training period, *Sdf*/*SDs* is the amplitude of fluctuations in the angle in the joint along the frontal/sagittal plane, *Vs*/*Vf* is the speed of articular angle fluctuations along the sagittal/frontal plane. Designations: KJ—knee joint, AJ—ankle joint, EO—eyes open; ^/\*/\*\* *p* < 0.1/0.05/0.01 compared to the initial period; *p* is the significance of differences between the groups.

“Control” group (+1.9; –4.0–5.3 s, *Me*: 25–75%, *p* = 0.18).

There were no significant correlations between the change in the time of retaining stability on the high see-saw with EC and the changes in anthropometry and strength indices during the period of strength training.

**Specific proprioceptive sensitivity.** The assessment of the accuracy of reproduction of the vertical body inclination in the ankle joint revealed no significant changes in the error in the reproduction of the COP and the error in the reproduction of angles in the HJ and AJ (Fig. 4) both in the “Control” and “Strength” groups after the strength training.

## DISCUSSION

The main goal of this work was to study the effect of strength training of the postural muscles of the lower limbs on the static and semi-dynamic balance of the one-leg posture in young subjects. The results of our study showed that the strength training does not have a significant effect on either the static or semi-dynamic stability of the one-leg posture. However, a steady trend towards a decrease in the amplitude and speed of fluctuations of the knee joint in the stance on the movable support was observed.

The amateur-level strength training program was effective in increasing strength, but not in increasing muscle mass. After the strength training, the speed of running to a distance of 12 m, as well as the number of

**Table 2.** Stabilographic and kinematic indices of the one-leg postural stability on the platform with eyes closed after 10 weeks of strength training, *Me* [25–75%]

Indices	“Strength”	“Control”	<i>p</i>
Center of pressure			
<i>V</i> -OTsD-EC, mm/s (before)	71.2 [58.0–81.5]	63.3 [51.3–71.6]	0.416
<i>V</i> -OTsD-EC, mm/s (after)	67.6 [48.7–84.4]	59.11 [43.6–74.4]	0.371
$\Delta V$ -COP-EC, %	–4.6 [–22.9–10.1]	–4.7 [–16.0–6.4]	0.914
<i>S</i> -COP-EC, mm <sup>2</sup> (before)	813 [686–1322]	724 [521–1088]	0.498
<i>S</i> -COP-EC, mm <sup>2</sup> (after)	692 [605–1179]	679 [504–1027]	0.551
$\Delta S$ -COP-EC, %	–13.5 [–27.9–17.6]	–5.1 [–19.0–15.3]	0.570
Knee joint			
<i>SD</i> s-KJ-EC, deg (before)	1.35 [0.58–1.91]	1.46 [0.83–2.32]	0.735
<i>SD</i> s-KJ-EC, deg (after)	0.97 [0.65–1.52]	1.05 [0.74–0.80]	0.456
$\Delta SD$ s-KJ-EC, %	–37.7 [–59.3–47.7]	–12.1 [–34.1–11.7]	0.626
<i>V</i> s-KJ-EC, deg/s (before)	5.44 [3.29–7.43]	4.16 [3.57–5.49]	0.371
<i>V</i> s-KJ-EC, deg/s (after)	4.79 [3.23–6.35]	4.14 [3.14–5.72]	0.524
$\Delta V$ s-KJ-EC, %	–10.9 [–29.4–12.03]*	–3.4 [–13.8–8.17]	0.303
Ankle joint			
<i>SD</i> s-AJ-EC, deg (before)	1.15 [0.79–1.71]	1.07 [0.86–0.53]	0.860
<i>SD</i> s-AJ-EC, deg (after)	1.34 [0.73–1.81]	1.12 [0.91–1.38]	0.787
$\Delta SD$ s-AJ-EC, %	5.6 [–28.6–98.6]	17.3 [–35.0–57.0]	0.828
<i>SDF</i> -AJ-EC, deg (before)	3.56 [1.88–6.85]	3.49 [2.70–4.68]	0.807
<i>SDF</i> -AJ-EC, deg (after)	3.26 [1.54–4.70]	3.42 [2.58–3.99]	0.588
$\Delta SDF$ -AJ-EC, %	–18.8 [–38.6–4.0]**	–5.3 [–23.3–14.1]	0.233
<i>Vf</i> -AJ-EC, deg/s (before)	14.70 [12.0–28.4]	16.50 [12.0–18.8]	0.725
<i>Vf</i> -AJ-EC, deg/s (after)	12.45 [7.91–21.22]	14.73 [8.90–18.03]	0.903
$\Delta Vf$ -AJ-EC, %	–20.1 [–33.7–2.3]**	–10.4 [–19.9–14.8]	0.267
<i>V</i> s-AJ-EC, deg/s (before)	4.95 [3.71–8.20]	4.10 [3.41–5.22]	0.198
<i>V</i> s-AJ-ECc, deg/s (after)	5.26 [4.14–7.25]	4.76 [3.31–6.32]	0.343
$\Delta V$ s-AJ-EC, %	–8.1 [–28.9–32.5]	1.4 [–16.0–34.4]	0.432

Designations: EC—eyes closed. For other designations, see Table 1.

flexions and extensions of the legs in the knee joint with submaximal weight increased. However, there were no significant differences in FFM and FM of the limbs compared to the “Control” group. Therefore, the increase in the strength abilities was mainly due to the improvement of the central nervous factors regulating the strength of the trained muscles (for example, an increase in the frequency of nerve impulses, recruitment of motor units, intermuscular coordination of contractions, and other processes). Indeed, it was shown that the increase in the muscle strength after the first 2 months of training was due mainly to neural adaptations rather than to muscle hypertrophy [11].

**Strength training and static postural stability.** Static balance is the ability to maintain the COP within a fixed and immovable support base (for example, on a

solid support) [9, 12]. We measured the static stability of the posture in the one-leg stance on the non-dominant limb, because this is a more difficult task for balance requiring significant activation of the postural system as compared to the two-leg position. The one-leg balance time is a reliable marker for detecting postural deficits and a predictor of falls in the elderly [13].

The results showed that the course of strength training in a stance on a platform with EO led to a decrease in *V*-COP ( $p < 0.05$ ) and stabilization of the ankle joint in the frontal plane: both *SDF*-AJ ( $p < 0.05$ ) and *Vf*-AJ ( $p < 0.01$ ) decreased. However, these positive changes did not differ from the changes in the “Control” group. Although we found no significant changes in the stabilographic indices during the training period in the stance with EC, the stability of the knee and ankle joints increased. However, these

**Table 3.** Changes in stabilographic and kinematic indices of postural stability on the low see-saw with eyes open after 10 weeks of strength training, *Me* [25–75%]

Indicators	“Strength”	“Control”	<i>p</i>
Center of pressure			
<i>V</i> -COP SS-EO, mm/s (before)	38.7 [27.5–43.3]	34.9 [31.6–40.0]	0.570
<i>V</i> -COP-SS-EO, mm/s (after)	35.1 [25.1–40.3]	30.7 [26.4–36.5]	0.787
$\Delta V$ -COP-SS-EO, %	–8.9 [–15.6–4.1]*	–16.5 [–20.7–3.1]**	0.330
<i>S</i> -COP-SS-EO, mm <sup>2</sup> (before)	338 [224–402]	361 [236–479]	0.892
<i>S</i> -COP-SS-EO, mm <sup>2</sup> (after)	314 [274–351]	222 [175–321]	0.151
$\Delta S$ -COP-SS-EO, %	–12.6 [–33.5–28.8]	–23.0 [–54.0–14.7]*	0.401
Knee joint			
<i>SD</i> s-KJ-SS-EO, deg (before)	0.82 [1.45–1.11]	0.61 [1.54–0.79]	0.136
<i>SD</i> s-KJ-SS-EO, deg (after)	0.56 [0.40–1.04]	0.72 [0.62–1.04]	0.162
$\Delta SD$ s-KJ-SS-EO, %	–34.4 [–67.5–5.2]**	1.3 [–37.9–25.7]	0.098
<i>V</i> s-KJ-SS-EO, deg/s (before)	3.52 [2.73–5.16]	2.37 [1.92–3.22]	0.036
<i>V</i> s-KJ-SS-EO, deg/s (after)	2.46 [1.88–3.16]	2.12 [1.84–3.27]	0.855
$\Delta V$ s-KJ-SS-EO, %	–20.7 [–49.6–10.9]**	–12.1 [–29.8–37.3]	0.062
Ankle joint			
<i>SD</i> s-AJ-SS-EO, deg (before)	1.48 [1.00–1.77]	1.71 [1.03–2.12]	0.508
<i>SD</i> s-AJ-SS-EO, deg (after)	1.47 [0.88–1.64]	1.34 [0.93–1.70]	1.000
$\Delta SD$ s-AJ-SS-EO, %	–12.0 [–36.5–19.9]	–11.3 [–42.3–23.8]*	0.704
<i>SDf</i> -AJ-SS-EO, deg (before)	1.65 [1.26–2.45]	1.71 [1.37–2.10]	0.921
<i>SDf</i> -AJ-SS-EO, deg (after)	1.55 [1.00–2.04]	1.57 [0.97–1.88]	1.000
$\Delta SDf$ -AJ-SS-EO, %	–9.4 [–39.2–2.5]*	–14.2 [–36.4–2.9]^	0.811
<i>Vf</i> -AJ-SS-EO, deg/s (before)	6.45 [4.83–9.68]	6.62 [5.27–9.34]	0.899
<i>Vf</i> -AJ-SS-EO, deg/s (after)	4.95 [3.34–7.17]	6.92 [3.54–8.07]	0.375
$\Delta Vf$ -AJ-SS-EO, %	–20.6 [–36.9–2.5]**	–16.0 [–30.7–0.8]^	0.508
<i>V</i> s-AJ-SS-EO, deg/s (before)	5.16 [3.28–6.08]	4.53 [3.52–6.28]	0.499
<i>V</i> s-AJ-SS-EO, deg/s (after)	3.98 [3.28–4.97]	4.22 [2.95–5.81]	0.910
$\Delta V$ s-AJ-SS-EO, %	–16.3 [–28.8–9.2]**	–19.62 [–30.0–2.6]*	0.855

Designations: SS—see-saw, EO—eyes open. For other designations, see Table 1.

changes also did not differ from the changes in the “Control” group. Thus, the increase in the strength abilities of the lower limbs after the course of strength training had no significant effect on the increase in the static stability of the vertical posture, and the decrease in the fluctuations in the COP and joints in the groups may be due to the learning effect associated with the repetition of the set of balance tests during testing.

The strength training caused no significant increase in the semi-dynamic balance of the one-leg posture in the stance on the low see-saw with EO and EC. In addition, despite the significant increase in the time of maintaining the balance of the posture on the high see-saw (on average by 3.8 s,  $p = 0.040$ ; Fig. 3) after the training program, no differences from the “Control” group were found as well.

These results are consistent with the data of other authors, who, like us, revealed no positive changes in the static stability in conventional postural tests (in two-leg and one-leg stances) after strength-oriented programs [5, 9, 14].

In particular, the authors of [14] revealed no increase in the static stability in two-leg and one-leg stances in elderly subjects after interval training and a simultaneous increase in the peak power in the maximum bicycle ergometric test. The authors of [9] compared the effect of strength and proprioceptive training on static, semi-dynamic, and dynamic balance in healthy young subjects. The authors found that neither strength nor proprioceptive training caused an improvement in the static one-leg balance; however, the semi-dynamic and dynamic balance was significantly improved. Another study [5] showed a *paradox-*



**Table 4.** Changes in stabilographic and kinematic indices of postural stability on the low see-saw with eyes closed after 10 weeks of strength training, *Me* [25–75%]

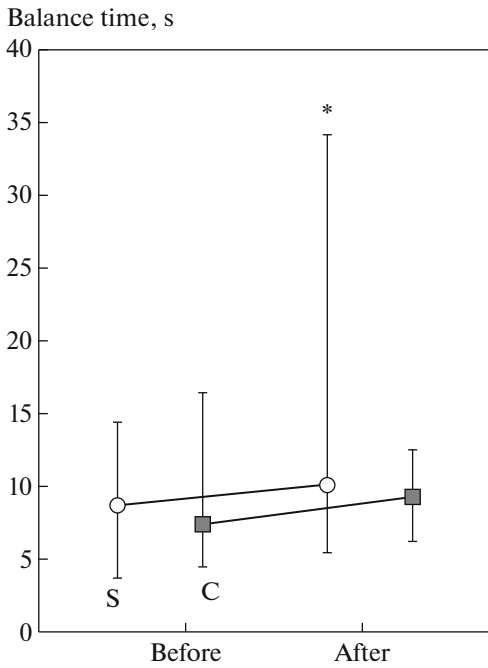
Indicators	“Strength” ( <i>n</i> = 10)	“Control” ( <i>n</i> = 11)	<i>p</i>
Common center of pressure			
<i>V</i> -COP-SS-EC, mm/s (before)	78.5 [70.8–101.5]	84.5 [72.2–104.1]	0.699
<i>V</i> -COP-SS-EC, mm/s (after)	83.0 [67.0–88.8]	89.1 [64.9–103.7]	0.504
$\Delta V$ -COP-SS-EC, %	–4.2 [–15.3–10.2]	–1.9 [–13.1–4.3]	0.916
<i>S</i> -COP-SS-EC, mm <sup>2</sup> (before)	1944 [1220–2566]	1846 [1226–2521]	0.972
<i>S</i> -COP-SS-EC, mm <sup>2</sup> (after)	1612 [1267–1790]	1816 [1629–2622]	0.098
$\Delta S$ -COP-SS-EC, %	–27.2 [–42.4–3.4] <sup>^</sup>	–1.7 [–26.0–20.3]	0.130
Knee joint			
<i>SD</i> s-KJ-SS-EC, deg (before)	1.60 [1.02–2.10]	1.78 [1.15–3.17]	0.903
<i>SD</i> s-KJ-SS-EC, deg (after)	1.84 [1.00–3.04]	2.79 [1.55–3.88]	0.307
$\Delta SD$ s-KJ-SS-EC, %	–12.2 [–46.9–58.8]	37.8 [0.9–118.0]	0.079
<i>V</i> s-KJ-SS-EC, deg/s (before)	7.30 [6.53–9.59]	7.46 [5.86–8.98]	0.967
<i>V</i> s-KJ-SS-EC, deg/s (after)	6.62 [4.97–7.88]	7.42 [5.23–11.18]	0.307
$\Delta V$ s-KJ-SS, %	–20.0 [–30.6–7.9]*	7.2 [–23.3–26.7]	0.079
Ankle joint			
<i>SD</i> s-AJ-SS-EC, deg (before)	3.82 [2.94–5.12]	4.55 [3.65–5.19]	0.597
<i>SD</i> s-AJ-SS-EC, deg (after)	3.67 [3.23–4.16]	4.13 [3.65–4.53]	0.170
$\Delta SD$ s-AJ-SS-EC, %	–13.2 [–39.6–24.5]	–0.4 [–18.7–20.6]	0.549
<i>SDf</i> -AJ-SS-EC, deg (before)	5.15 [3.30–6.03]	5.11 [3.67–5.99]	0.860
<i>SDf</i> -AJ-SS-EC, deg (after)	3.70 [2.54–4.67]	4.13 [2.92–5.94]	0.170
$\Delta SDf$ -AJ-SS-EC, %	–22.8 [–37.5–1.5]*	–19.2 [–36.2–32.7]	0.504
<i>Vf</i> -AJ-SS-EC, deg/s (before)	19.06 [15.35–20.68]	18.97 [16.58–22.38]	0.916
<i>Vf</i> -AJ-SS-EC, deg/s (after)	14.61 [12.83–16.43]	16.66 [12.59–24.64]	0.418
$\Delta Vf$ -AJ-SS-EC, %	–21.1 [–29.8–4.3]*	–17.6 [–32.9–9.1]	0.860
<i>V</i> s-AJ-SS-EC, deg/s (before)	12.27 [11.96–17.64]	14.09 [10.47–16.64]	0.972
<i>V</i> s-AJ-SS-EC, deg/s (after)	11.91 [11.33–13.70]	13.08 [10.34–15.88]	0.597
$\Delta V$ s-AJ-SS-EC, %	–5.9 [–29.4–5.5]	–3.1 [–21.4–17.5]	0.460

Designations: SS—see-saw, EC—eyes closed. For other designations, see Table 1.

*ically smaller effect* ( $\approx 1\%$ ) of high strength loads compared to the effect ( $\approx 10\%$  improvement) of training with low resistance but with a maximum rate of exercise in improving the semi-dynamic balance in healthy elderly individuals. The authors suggested that the speed of muscle contraction is more important for postural regulation than the maximum strength or strength endurance. The absence of the effect of 2-week ballistic training of leg muscles on static and dynamic balance, despite an increase in strength indices, was also shown in adolescents 15–17 years old [15]. A systematic review of 37 studies showed weak correlations in children ( $r = 0.11$ ,  $p = \text{n.d.}$ ) and in young ( $r = 0.20$ ,  $p = 0.07$ ) and elderly healthy individuals ( $r = 0.27$ ,  $p < 0.001$ ) between indices of strength or power and static stability of the one-leg posture [16].

Despite the correlations, the authors concluded that the strength and postural abilities were independent.

*Mechanisms underlying the absence of the effect of strength training on postural balance.* The absence of the effect of the increased strength abilities of the postural muscles of the legs on the static and semi-dynamic stability of the posture may be determined by the following factors. First, an increase in the strength abilities beyond the minimum required threshold probably has no additional effect on the vertical posture control. Under normal standing conditions, low strength abilities are required to maintain the balance; therefore, the maximum strength reserve is not used to maintain the static balance [1, 9]. As a rule, the correlation between the strength of the postural muscles and postural fluctuations manifests itself at initially reduced strength abilities of the postural muscles—in

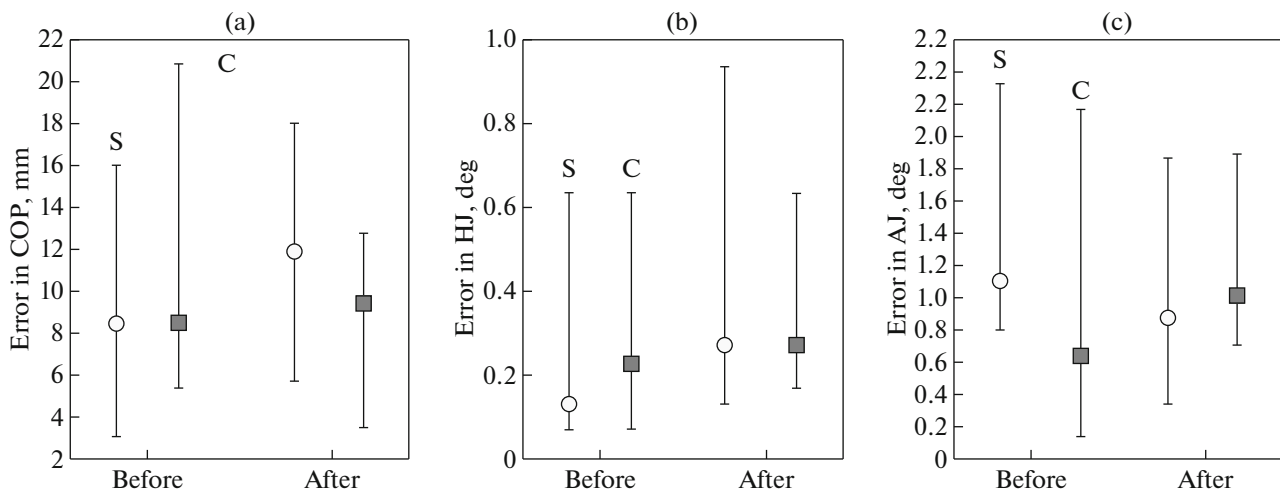


**Fig. 3.** Changes in the stability of a one-leg stance on the high see-saw with eyes closed after the course of strength training. Designations: S—group “Strength”, C—group “Control”, \*  $p < 0.05$  compared to the values before training. The difference between the changes in the balance time in the groups according to the Mann–Whitney test was  $p = 0.18$ .

the elderly or in diseases that are accompanied by sarcopenia/physical inactivity [4–6]. Since our experiment involved young physically active girls with a normal level of strength abilities of leg muscles, additional strength training had no significant effect in postural regulation.

Second, the neural adaptations induced by strength exercise apparently are not used by the postural regulation system during balance tasks due to their specificity to training exercises. Indeed, posture regulation is to a greater extent based on the concordance and efficiency of sensorimotor processes in the control of postural muscles but not on the ability to maximize contractions. Strength training leads to neural adaptations that differ from the rearrangements induced by specific postural training [17, 18]. For example, strength training causes an increase in the excitability of  $\alpha$ -motoneurons in unusual postural tests. Conversely, after balance training, the excitability in postural tests [17, 18] or the reflex activity in response to mechanical stretching of the calf muscles [19] decrease. The specificity of rearrangements in the excitability of  $\alpha$ -motoneurons is largely due to descending cortical–spinal influences (an increase or decrease in inhibition of the activity of Ia-afferents during postural tasks after balance training and strength training, respectively). Similarly, the excitability of  $\alpha$ -motoneurons decreases with an increase in the coordination complexity of postural tasks from the supine position to the normal stance and to the tandem stance [20], although some authors did not find this dependence [21].

The independence of posture regulation from strength abilities was indirectly indicated by the absence of correlations between the changes in *stabilographic indices* in postural tests and the increase in strength abilities during the period of the experiment. We found only weak correlations ( $r = -0.30-0.40$ ,  $p < 0.1-0.02$ ) between the changes in the *kinematic* (amplitude and speed of fluctuations of the angles in the ankle joint in the stance on the platform and on the see-saw) and the changes in the strength indices



**Fig. 4.** Specific proprioceptive sensitivity after the course of strength training ( $Me [25-75\%]$ ). (a) Error in reproduction of the position of the center of pressure (COP). (b) Error in reproduction of the angle in the hip joint (HJ). (c) Error in reproduction of the angle in the ankle joint (AJ). Designations: S—group “Strength”, C—group “Control”.

(standing long jump and extension of the legs on the simulator).

Third, strength training caused no increase in the specific proprioceptive sensitivity in the test of vertical body inclination at the ankle joint. The error of reproduction of the COP, as well as the errors of reproduction of the angles in the HJ and AJ, did not change after the training program (Fig. 4). The proprioceptive sensitivity makes the largest contribution (approximately 70%) to the stability of the vertical posture under static standing conditions compared to the vestibular (10%) and visual (20%) sensory systems [22]. Therefore, the strength training was ineffective in improving the somatosensory factor of postural stability, which also indicates a weak effect of strength training on the ability to postural balance.

Our results are confirmed by the published data. Usually, specific exercises showing biomechanical similarity with the test balance tasks have a significant effect on the posture regulation [23]. On the contrary, exercises different from those used in the study have either little or no effect on the tested postural abilities [16, 24]. Therefore, the neuromuscular adaptations provided by strength training are apparently ineffective in improving postural regulation.

Despite the absence of an increase in the stabilographic indices of postural stability, the strength training led to a decrease in the amplitude ( $p < 0.05$ ) and speed ( $p < 0.05$ ) of fluctuations in the knee joint in the stance on a mobile support with EO and EC. The dynamics of these indices differed between the groups at a trend level ( $p < 0.09$ – $0.06$ ). Since the amplitude and especially the speed of fluctuations in the joints of the supporting limbs increased with an increase in the complexity of tests for the vertical posture balance [25], the decrease in  $SD$ -KJ and  $V$ -KJ in the stance on the see-saw is a positive adaptation aimed at increasing postural stability. Usually, an increase in the stability of joints increases the postural stability under difficult standing conditions [9]. However, in our study, the increase in the stability of the knee joint during the stance on the movable support was insufficient to increase the entire posture stability. This probably requires additional mechanisms that improve the neuromuscular regulation in other joints of the body and limbs (first of all, in the ankle joint).

## CONCLUSIONS

Strength training of the postural muscles of the lower limbs in young healthy subjects contributes to an increase in the stability of the knee joint in a stance on a movable support but has almost no effect on the static (i.e., in a stance on a stable platform) and semi-dynamic (i.e., in a stance on a movable see-saw) postural balance and does not change the specific proprioceptive sensitivity in the postural test. It can be assumed that the neuromuscular adaptations caused

by the strength exercises, which do not have biomechanical and dynamic similarities with postural balance exercises, cannot be directly used by the posture regulation system, at least in young subjects with a normal level of development of physical abilities.

## ACKNOWLEDGMENTS

We are grateful to E.A. Krosheva, Director of the State School (Technical School) of the Olympic Reserve for Ice Hockey in Yaroslavl, for help in organizing the experiment.

## COMPLIANCE WITH ETHICAL STANDARDS

*Conflict of interest.* The authors declare the absence of obvious and potential conflicts of interest related to the publication of this article.

*Statement of compliance with standards of research involving humans as subjects.* All studies were carried out in accordance with the principles of biomedical ethics formulated in the Declaration of Helsinki 1964, its subsequent updates and approved by the local bioethical committee of Ushinsky Yaroslavl State Pedagogical University (Yaroslavl). Each study participant provided voluntary written informed consent to participate in the upcoming experimental study.

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Translated by M. Batrukova