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LONG-TERM RESEARCH OF SCHOOLCHILDREN SPINAL CORD MOBILITY: AGE ASPECTS AND ENHANCEMENT METHODS

BADANIE DŁUGOOKRESOWE RUCHOMOŚCI RDZENIA KRĘGOWEGO U DZIECI W WIEKU SZKOLNYM: ASPEKTY ZWIĄZANE Z WIEKIEM I METODY JEJ POPRAWY

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Authors' contribution
Wkład autorów:
A. Study design/planning
zaplanowanie badań
B. Data collection/entry
zebranie danych
C. Data analysis/statistics
dane – analiza i statystyki
D. Data interpretation
interpretacja danych
E. Preparation of manuscript
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F. Literature analysis/search
wyszukiwanie i analiza literatury
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Summary

Background. The aim of this research was to reveal the age-related characteristics of schoolchildren spinal cord mobility changes and experimentally substantiate the methods of their improvement in the long-term process of physical education.
Material and methods. The two age groups were simultaneously investigated: primary school (1-4th grades) and secondary school (5-9th grades) children. The author's methods of schoolchildren spinal mobility improvement were included in the physical education lessons of the trial groups, while in the control groups, the lesson was conducted according to the school curriculum.
Results. The results of the long-term study revealed features of spinal mobility indicator dynamics at the stage of school ontogenesis. The data of annual testing demonstrates an improvement in the indicators of spinal mobility among the male and female schoolchildren of the experimental groups. The results obtained in the control group show that at the stage of school ontogenesis, their deterioration is possible.
Conclusions. This underpins the assertion that a factor of great significance in improving spinal mobility is not the peculiarities of age-related development but the special method. Thus, the necessity to include a special set of exercises aimed at improving spinal mobility, in the content of a school curriculum in physical education, was confirmed.
Keywords: spinal mobility, schoolchildren, longitudinal studies, physical exercises

Streszczenie

Wprowadzenie. Celem badania było poznanie związanych z wiekiem cech zmian ruchomości rdzenia kręgowego u dzieci w wieku szkolnym oraz eksperymentalne uzasadnienie metod ich poprawy w ramach prowadzonych przez wiele lat zajęć wychowania fizycznego.
Materiał i metody. Jednocześnie badano dwie grupy wieku: dzieci ze szkół podstawowych (klasy 1 do 4) i z gimnazjum (klasy 5 do 9). Autorskie metody usprawniania ruchomości kręgosłupa dzieci w wieku szkolnym stosowano na lekcjach wychowania fizycznego w klasach będących przedmiotem badania, natomiast w klasach kontrolnych zajęcia odbywały się zgodnie ze szkolnym programem nauczania.
Wyniki. Wyniki badania długookresowego pozwoliły na ujawnienie cech dynamiki wskaźnika ruchomości kręgosłupa na etapie ontogenezy u dzieci w wieku szkolnym. Dane z przeprowadzanych corocznie badań wskazują na poprawę wskaźników ruchomości kręgosłupa wśród uczniów i uczennic klas będących przedmiotem badania. Wyniki uzyskane w grupie kontrolnej wskazują, że na etapie ontogenezy u dzieci w wieku szkolnym może dojść do ich pogorszenia.
Wnioski. Stanowi to podstawę twierdzenia, że czynnikiem mającym duże znaczenie w poprawie ruchomości kręgosłupa nie są osobliwości rozwoju związane z wiekiem, ale specjalna metoda. Tym samym potwierdzono konieczność włączenia specjalnego zestawu ćwiczeń poprawiających ruchomość kręgosłupa do szkolnego programu realizacji wychowania fizycznego.
Słowa kluczowe: ruchomość kręgosłupa, dzieci w wieku szkolnym, badania długookresowe, zajęcia ruchowe

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Introduction

The functional condition of the spinal cord refers to the most relevant medical and social-pedagogical issues of the modern world, yet it is considered to be not only one of the factors defining certain position of the human body in space, but also an important determinant of human health [1-3]. Numerous studies on school age children's motor system condition provide evidence that this problem does not lose its relevance and value with age. According to data from literary sources, the prevalence of posture disorders rises 5 times throughout school education [4,5]. There, 96% of all deviations from normal posture in school age children are related to dysfunction and pathological processes of skeletal muscles and only 4% is accounted for by congenital scoliosis and kyphosis [5]. Spinal cord deformation develops in children of any age before the end of the growth, but most frequently (about 75%) it is seen in children of 8-14 years old. It should be noted that improvement of education system in modern conditions is related to the introduction of new informational technologies, the most important part of which is the computerization of the learning process. Students spend many hours a day in front of computer. This increases the load on the spinal cord, associated with the enforced maintenance of a long-time sitting posture [6,7]. The cervical and thoracic spines undergo considerable overload.

The studies of Gheysvandi et al. [8] have shown that neck and shoulder pain is common in children and teenagers, which also has a negative impact on their physical and mental health. According to data from Khvisyuk et al. [9] in adolescence and youth, the worsening of spinal cord mobility and clinical signs of degenerative changes haven been noted. The studies of Rai et al. [10] and Hossain et al. [11] should also be noted, that raise the issue of heavy backpacks, which have an influence on the posture of primary and secondary school students and lead to back pain and postural traumas.

In this regard, a longitudinal study of the posture and mobility of the spine in the sagittal plane has been made, which was carried out on children at the age of 5-6 and again at the age of 15-16 [12]. Widhe [12] revealed an increase in kyphosis, a decrease in spinal mobility, and 38% of schoolchildren had cases of back pain.

It was found that it is of a particular importance to provide normal mobility of the spinal cord for the development of the right posture. Namely, spinal cord mobility can serve as one of hallmarks of not only its own, but also general body health, being to some extent its indicator [13].

Considering the fact that spinal cord development and its functional improvement undergo quite a long period of ontogenesis and ends at between 20 and 22 years old, it is important to reach a certain mobility of the spinal cord and to strengthen the muscular corset. This will create a basis for its normal function in subsequent years. Motor system function deviations at school age, that seem minor at first sight, may cause serious, sometimes irreversible structural disorders in adulthood and can lead to unsuitability. The higher the level of functional condition of the spinal cord and musculoskeletal system in childhood and youth, the longer it remains in adulthood.

The foresaid determines the significance of a complex solution to one of the main tasks of children's physical education for all sectors of population, aimed to develop the posture and "engineering" of the spinal cord and its mobility throughout a lifetime.

The purpose of this study is to discover the age features of spinal cord mobility changes in schoolchildren and experimentally justify its improvement methods in the process of physical education in the long term.

Material and methods

The following research methods were used in the work: a study and analysis of scientific and methodological literature, pedagogical tests, long-term experiment, and mathematical statistics.

To get the most complete picture that will characterize spinal cord mobility, the methods have been selected that allow to record the movements of the spine in all the planes.

To evaluate the spinal cord mobility in the sagittal plane, there were used:

- forward bends (in cm): standing on a gymnastic bench with legs straightened at knees, a forward bend is performed with fingers touching the mark below or above the zero point (it is at the level of the feet) and remaining in the pose for at least 2 seconds. If the fingers of the hands do not reach the level of the feet when bending forward, the results are assessed with a sign "-"; when reaching the point below the zero point, it is evaluated with a sign "+";
- back bends (deflection in cm): standing with their legs together, holding a gymnastic stick from the back below, the distance from the stick to the floor is measured in cm, then the subject bends backwards without bending their knees (for maximum possible painless performance, the child was slightly secured), also measuring the distance from the stick to the floor. When performing this test, it is important to keep your arms straight at the elbow joints. The difference between the two measurements was estimated in cm.

The mobility of the spine in the frontal plane (lateroflexion) was assessed using the method described by Moshkov. The subject stands with their back to the wall touching their shoulder, legs together, the back straight, and arms along the body. The distance from the tip of the middle finger of the right hand to the floor is measured. Then, the subject is asked to bend to the right, without moving their shoulders from the wall and the feet from the floor; meanwhile, the legs are still straight. The distance from the middle finger to the floor is also measured. The same task is done to the left side. The difference in measurement from the standing position and when bent to the side (in cm) is assessed.

To evaluate the rotational movements of the lumbar and cervical spines to left and right sides, the test developed by Hakobyan was used [14]. Its essence is: the subject in a sitting position with knees bent at a right angle and with fixation of the pelvis makes turns of the body to the right and to the left. The role of the arrow is performed with a gymnastic stick fixed strictly on the belt. The degree of deviation is measured. Using the same principle, a graduated collar is provided to determine the mobility of the cervical spine. The zero mark is set at the level of the midline of the chin. The subject turns their head to the right; the degree of deviation is fixed. The same is done on the left side. The indicators of strength endurance of the long muscles of the back, as well as the strength of the abdominal muscles in static and dynamic mode, is also recorded.

In order to determine the static endurance of the back muscles, the subject lies on their stomach on a bench in such a way that the edge of the bench is at the level of the wings of the ilium, and the trunk is without any support, while the hands are behind the head. On a signal, the subject raises their trunk and, straining the muscles of the back, holds it at a horizontal level. The legs are fixed at the same time. The retention time is recorded. If the trunk falls below the level of the horizontal line of the bench, the stopwatch stops. To determine the strength of the abdominal muscles, the subject was asked to hold the 45° angle from the initial sitting position while, at the same time, making sure that the knees did not bend. The retention time was recorded (static mode of operation). At the same time, the subject was asked to raise their straightened legs to an angle of 90° as many times as possible from a supine position with their hands behind their head (dynamic mode of operation).

The primary data of experimental studies were processed and analyzed using methods of mathematical statistics. At the same time, the task was to assess the degree of reliability and the reliability of quantitative and qualitative characteristics of the actual material and to identify patterns in the obtained indicators.

Depending on the type and analysis of the data obtained, the following were calculated:

X – arithmetic mean,

σ – the range of sigma fluctuations of the sample,

m – the error of the arithmetic mean,

t – the criterion of differences by student,

T – growth rate in % which is calculated by the formula: T=y1 /y0 100,

Δ – absolute growth of indicators,

Δ% – growth rates.

The statistic processing of the obtained results was carried out using Microsoft Excel 2010. To organize the pedagogical experiment, the method of long-term sections (long-term plan) was used, which allows to conduct repeatedly the planned studies over a set period of time on a specific group, in order to identify the ontogenetic features of changes in the mobility of the human spine.

Long-term studies were started in two age groups simultaneously, due to: first, opportunity to include different age groups of school ontogenesis: primary (1-4th grades) and secondary (5-9th grades) schools; second, disclosure of the features of spinal cord mobility improvement methods at each step of school education, correspondingly in two experimental and two control groups. Throughout the study, the author's spinal cord mobility improvement method was introduced in the trial classes (first and fifth), while, in the control classes, the physical education process was established in accordance with the current school program of physical education. Throughout the study, all the participants of the pedagogical experiment annually underwent a testing based on a special technique in April-May.

The longitudinal study enrolled 100 pupils from Yerevan city (Armenia) with 50 participants in each age group. In the younger age group (1-4th grades of primary school) – 50 schoolchildren took part in four-year long-term studies: 26 in the experimental group (13 girls and 13 boys) and 24 in the control group (12 girls and 12 boys). In the group of students from 5-9th grades (secondary school) – again, 50 schoolchildren took part in the five-year long-term study: 25 were in the experimental and 25 in the control group: 13 girls and 12 boys in each group.

A long-term pedagogical experiment was carried out in the natural conditions of the educational process at physical education lessons in secondary school. To carry out a long-term study, the permission was taken from the school director and the head of the educational department. Consultations on the methodology were held with the teacher of physical education, who conducted lessons in the experimental classes. It should also be stated that all the participants provided informed verbal consent regarding their involvement in the research.

Results

While working out the methods of spine mobility improvement, general methodical principles were followed, accepted in the theory and practice of physical education at schools. Additionally, physical exercises from Chinese gymnastics and yoga were applied, with stretching adapted to a given age. In this regard, the experience of foreign authors was also studied [15-17].

The base of physical exercises was developed for the students of secondary school, unlike the complex that was used in the primary school children, which consisted of exercises, classified to 2nd and 3rd levels [14]. Namely, exercises of the 3rd level that involve the whole spine, allow us to activate the fixed parts of the spine (thoracic, sacral), improve their trophic aspects and strengthen small muscle groups, as well as normalize the statics of the spine. In the clarification of spine mobility improvement methodological techniques, both the physical features of the body at that age and the postural muscles were reconsidered. In a given situation, the load regimen that corresponds to motor system working specificities is considered to be the most reasonable. The exercises included in the complex were made in dynamic and static regimens, attempting to balance them. This approach allows, on the one hand, to increase the movement amplitude in different parts of the spine, and to strengthen musculoskeletal system on the other.

While performing the exercises, following these rules was obligatory:

- the influence must be complex (on the whole spine, providing the unity of the common chain of spine and pelvis);
- distinct differentiation of efforts was made, their direction, as well as working regimens (static, dynamic and static-dynamic);
- exercises aimed at increasing mobility are essential to combine with exercises aimed at reinforcing the muscles that determine spine mobility, by normalization of their tone.

Following the unity of the rules and a flexible approach of exercise selection formed the base of the proposed methods. Exercises in the complex could change, but the basic principle was unchangeable: the principal of complex influence on the spine.

The recommended set of physical exercises was supposed to fit into the structure of a school physical education lesson and, at the same time, they were to correspond to the content of the program material. In this regard, the selected exercises were used in all the parts of the lesson: preparatory, main and final.

In the preparatory part of the lesson, the proposed exercises were included in a set of general developmental exercises, where exercises for the neck and head, as well as the trunk, were performed in accordance with methods and organization of their performance (involving precisely targeted muscle groups, certain joints and cords that require perfect accuracy of their performance).

To perform a special set of exercises, 5-7 minutes were given to the main part of the lesson, during which 5-6 exercises were performed. Depending on the content and direction of the lesson, the exercises were performed in pairs or as group exercises, at the gymnastic wall, from the initial position, sitting, lying, standing, and in the position on knees.

Taking into account the fact that a significant amount of time is devoted to outdoor games in the physical education program in primary grades, games contributing to the improvement of the mobility of the spine were specially selected.

The duration of the proposed exercises was determined by the general structure of the school lesson, as well as the specifics of the tasks being solved. The teacher was offered to choose those exercises that would best correspond to content of the lesson.

In the final part of the lesson, exercises were proposed (1 exercise for the cervical and thoracic spine and 1-2 for the lumbar spine), combining a restorative effect on the body and stretching exercises which were performed from the starting position while standing and “cross-legged” sitting.

During the long-term study, the results were collected that reflect both patterns of natural development of the body, spine mobility, and the effect of pedagogically directed influence. As expected, a certain dynamic of spine mobility and musculoskeletal system indicators of the school children were revealed during the pedagogical trial. These changes were controversial. The study revealed positive results in schoolchildren spine mobility indicators in the frontal plane. This tendency was seen both in the boys and girls. The improvement of spine mobility in the frontal plane was revealed in both groups; however, growth of indicators was higher in the trial group, as shown in Table 1. It should be noted that the highest growth speed was seen in the pupils of the 2nd to 4th grades (31.87% to the right and 9.31% to the left in the boys, correspondingly 56.95% and 50.74% in the girls); the greatest indicators in trunk lateral flexion were seen in the 8th grade boys: 22.89 cm to the right and 22.73 cm to the left; in the 9th grade girls – 23.28 cm to the right and 24.05 cm to the left. At the same time, by the end of the pedagogical experiment, significant changes in the studied indicators between the trial and control groups were revealed only in the boys of the 1st group ($t=2.07$, $p<0.05$).

Table 1. Dynamics of the schoolchildren's spinal mobility in the frontal plane in the longitudinal section (X±m)

1st group							
Indicators	**Groups**	**1st grade**	**2nd grade**	**3rd grade**	**4th grade**	**Δ**	**Δ%**
Boys							
Tilt to the right (cm)	**Trial**	15.0±0.86	15.0±1.12	17.54±1.18	19.78±0.74	4.78	31.87
	T %	-	0	16.93	12.77		
	Control	14.6±1.39	14.62±1.32	17.18±0.82	17.92±0.49	3.32	22.74
	T %	-	0.14	17.51	4.31		
Tilt to the left (cm)	**Trial**	14.5±1.3	15.0±1.22	18.18±1.21	20.2±1.12	5.7	39.31
	T %	-	3.45	21.2	11.11		
	Control	14.28±0.94	14.3±1.03	17.0±0.45	18.0±0.48	3.72	26.05
	T %	-	0.14	18.88	5.88		
Girls							
Tilt to the right (cm)	**Trial**	12.45±0.54	14.91±1.25	17.78±1.27	19.54±1.37	7.09	56.95
	T %	-	19.25	23.05	9.89		
	Control	15.54±0.95	16.0±0.95	16.7±0.92	18.5±0.59	2.96	19.05
	T %	-	2.96	4.5	11.59		
Tilt to the left (cm)	**Trial**	12.91±0.78	15.09±1.11	17.78±1.29	19.46±1.32	6.55	50.73
	T %	-	16.89	9.45	13.01		
	Control	14.92±0.75	15.71±0.89	16.3±0.67	18.62±0.8	3.7	24.79
	T %	-	5.29	3.75	14.23		
2nd group							
Indicators	**Groups**	**5th grade**	**6th grade**	**7th grade**	**8th grade**	**9th grade**	**Δ**	**Δ%**
Boys							
Tilt to the right (cm)	**Trial**	20.9±1.0	21.73±0.94	22.33±0.87	22.89±1.7	22.86±2.14	1.96	9.38
	T %	-	3.97	2.76	2.5	-0.14		
	Control	20.33±2.6	20.53±0.83	21.6±3.11	22.71±1.69	22.42±1.69	2.09	10.28
	T %	-	0.98	5.21	5.14	-1.43		
Tilt to the left (cm)	**Trial**	19.0±3.6	21.54±0.89	22.09±0.87	22.73±1.51	22.44±1.44	3.44	18.10
	T %	-	13.37	2.55	2.89	-1.53		
	Control	19.64±1.27	20.6±0.67	21.4±3.04	22.64±1.55	22.09±0.87	2.45	12.47
	T %	-	4.89	3.88	5.79	-2.8		
Girls							
Tilt to the right (cm)	**Trial**	18.79±1.21	20.9±1.0	21.8±1.15	22.5±0.90	23.28±1.5	4.49	23.89
	T %	-	11.23	4.30	3.21	3.47		
	Control	19.61±0.84	20.55±1.14	21.25±1.08	21.71±2.22	22.33±1.0	2.72	13.87
	T %	-	4.79	3.41	2.16	2.85		
Tilt to the left (cm)	**Trial**	18.83±1.27	21.25±1.08	22.3±0.94	22.97±1.1	24.05±1.75	5.22	27.72
	T %	-	12.85	4.94	3.00	4.7		
	Control	19.5±0.73	20.22±1.05	21.62±1.08	22.12±0.94	22.17±1.03	2.67	13.69
	T %	-	3.69	6.92	2.31	0.22		

Notes: X-average value, m – mean error, T – compound annual growth rate.

The indicators of the spinal mobility in the sagittal plane are controversial (Table 2). Although there was some improvement in the values of the forward lean in the boys and girls in the trial groups, it should be stated that the general results of this test didn't match age norms. Through years of observation, the boys from the control groups achieved forward lean results with "minus" sign. As for forward lean indicators growth speed,

both in the girls and in the boys, a radical dynamic of results was seen. Throughout the pedagogical trial, the greatest yearly growth speed in given test exercises was recorded in the trial groups: in the girls in 2nd, 6th, 7th and 9th grades and boys in the 2nd, 3rd and 6th grades.

The picture of the spinal mobility indicators dynamics in trunk backward lean varied. In the given exercise, the regular growth of results with age was revealed both in the boys and girls. It's notable that, unlike forward lean, yearly growth of these indicators is less significant; in the girls, it's more expressed than with respect to the boys.

The best results in trunk back lean were recorded in the 9th grade girls: 19.5±1.55 cm; in the boys, the peak accounted for the 8th grade and was 15.33±2.15 cm, after which some worsening of the results followed.

Table 2. Dynamics of schoolchildren's spine mobility in the sagittal plane in the longitudinal section (X±m)

1st group							
Indicators	**Groups**	**1st grade**	**2nd grade**	**3rd grade**	**4th grade**	**Δ**	**Δ%**
Boys							
Tilt forward (cm)	**Trial**	-7.73±2.92	-4.3±1.62	0.75±1.79	1.73±1.43	9.46	122.38
	T %	-	44.37	65.33	12.68		
	Control	-6.0±2.31	-5.92±2.04	-3.18±2.87	-1.77±1.78	4.23	70.5
	T %	-	1.33	45.67	23.5		
Tilt back (cm)	**Trial**	8.36±1.18	9.82±0.75	11.86±1.93	12.36±1.08	4.0	47.85
	T %	-	17.46	24.41	5.98		
	Control	9.69±0.86	10.28±1.49	10.69±0.86	12.0±0.56	2.31	23.84
	T %	-	6.09	4.23	13.52		
Girls							
Tilt forward (cm)	**Trial**	-7.93±1.9	-3.09±2.26	-2.0±1.79	-1.45±1.97	6.48	81.71
	T %	-	61.03	13.75	7.93		
	Control	-7.4±2.0	-5.38±1.72	-2.5±1.79	-1.89±2.01	5.51	74.46
	T %	-	27.29	38.93	8.24		
Tilt back (cm)	**Trial**	8.82±0.92	9.8±0.96	10.25±1.37	11.33±0.96	2.51	28.46
	T %	-	11.11	5.1	12.25		
	Control	9.15±0.91	9.28±0.92	10.1±0.89	10.89±1.28	1.74	19.02
	T %	-	1.42	8.96	8.64		
2nd group							
Indicators	**Groups**	**5th grade**	**6th grade**	**7th grade**	**8th grade**	**9th grade**	**Δ**	**Δ%**
Boys								
Tilt forward (cm)	**Trial**	-6.54±3.18	-4.45±2.56	-2.78±2.84	-1.6±3.26	-1.5±3.05	5.04	77.06
	T %	-	46.97	10.49	18.07	1.53		
	Control	-5.07±2.62	-5.9±3.19	-5.8±3.16	-5.5±3.25	-6.67±8.84	-1.6	31.56
	T %	-	-16.37	1.98	5.91	-23.08		
Tilt back (cm)	**Trial**	12.36±1.39	13.0±3.0	14.11±1.27	15.33±2.15	14.94±1.42	2.58	20.87
	T %	-	5.18	8.98	9.87	-3.16		
	Control	11.54±1.11	12.7±0.97	13.4±1.03	14.0±1.21	13.64±0.92	2.1	18.19
	T %	-	10.05	6.07	5.2	-3.13		
Girls								
Tilt forward (cm)	**Trial**	-1.83±2.67	0.5±1.31	1.81±1..19	2.44±1.27	4.0±2.11	5.83	318.58
	T %	**-**	127.32	71.59	34.42	85.25		
	Control	**-1.92±3.42**	-0.5±3.29	-0.22±1.91	-0.17±2.12	0.5±3.23	2.42	126.04
	T %	**-**	73.96	14.58	2.61	34.89		

Tilt back (cm)	**Trial**	13.44±1.26	15.25±1.26	16.33±2.10	17.2±1.24	19.5±1.55	6.06	45.09
	T %	-	13.47	7.08	5.33	13.37		
	Control	**14.44±1.89**	14.94±1.41	15.25±1.52	15.67±1.01	15.75±1.84	1.31	9.07
	T %	-	3.46	2.07	2.75	0.51		

Notes: X-average value, m – mean error, T – compound annual growth rate.

At the same time, it should be noted that the differences in the indicators characterizing the mobility of the spine in the sagittal plane, obtained during a long pedagogical experiment, are not reliable in the boys and girls of the two age groups: experimental and control (p>0.05).

It should be mentioned that the most significant difference in spine rotational mobility was revealed in the study. The worsening of the rotational mobility of the cervical spine in control groups both in the boys and girls, beginning from the third grade, is shown in Table 3.

Table 3. The dynamic of the cervical spine rotational mobility in the long term (X±m)

Grades		**Neck rotation (degrees)**			
		Right	**Left**	**Right**	**Left**
		Boys		**Boys**	
1st group					
1st grade	**Trial**	74.33±1.28	74.37±3.33	74.45±2.73	74.09±2.11
	Control	74.28±2.09	74.71±1.7	74.71±1.7	74.71±1.7
2nd grade	**Trial**	74.37±3.59	74.5±2.59	76.07±1.4	75.0±1.51
	Control	73.0±1.6	75.0±1.39	72.69±1.56	72.69±1.56
3rd grade	**Trial**	75.0±1.56	74.89±2.11	76.36±1.66	75.71±1.64
	Control	71.5±1.67	72.5±2.11	71.87±1.31	71.87±1.31
4th grade	**Trial**	75.4±1.68	75.3±2.59	73.85±1.28	73.85±1.4
	Control	71.11±3.09	70.9±2.41	68.93±2.04	68.93±2.04
2nd group					
5th grade	**Trial**	70.45±2.07	70.02±2.4	74.0±2.21	73.5±2.36
	Control	70.0±1.57	69.0±2.55	73.65±2.33	72.67±2.0
6th grade	**Trial**	73.5±2.11	73.33±2.13	75.62±3.19	75.25±2.63
	Control	72.14±1.55	72.08±2.17	70.31±2.21	70.42±2.17
7th grade	**Trial**	74.28±2.29	74.2±2.24	74.58±2.57	74.58±2.57
	Control	70.55±2.11	70.85±2.85	68.89±2.17	69.44±1.94
8th grade	**Trial**	74.54±3.53	74.09±3.08	74.17±2.29	74.0±2.19
	Control	68.45±2.2	67.0±2.45	67.78±2.22	67.92±4.67
9th grade	**Trial**	72.5±2.14	71.67±1.89	73.33±2.89	72.86±1.92
	Control	66.82±1.55	66.82±1.55	67.5±2.5	65.55±2.42

Notes: X – average value, m – mean error.

The cervical spine, according to Khvisyuk et al., is the most vulnerable and susceptible to early destructive changes [9]. For that reason, its workout, started in primary school age, along with continuous intensive body growth, allows to preserve or even improve cervical spine mobility, and, at the same time, to provide for its and the whole spine's essential functionality. The results of long-term observations in trial groups lead to the conclusions about the ability to maintain rotational mobility of the cervical spine throughout school ontogenesis. Minor worsening of these indicators in the 9th grade tells more about the regimen and nature of movement activity of ninth graders than cervical spine functionality features. The study identified reliable differences between the investigated indicators in the boys of the 9th grade in the control and trial groups (neck right rotation: t=2.14,

$p<0.05$; left rotation: t=2.21, $p<0.05$). The reliable differences in cervical spine rotational movements to the left were noted between the groups in the girls (t=2.36, $p<0.05$). A distinctive feature of the dynamics of cervical spine rotational mobility results is the minor annual growth of these indicators, which was found both in the boys and girls.

A study of lumbar spine rotational mobility results in an improvement of given indicators both in the boys and girls until the 8th grade, after which their worsening was observed. Therefore, the character of regression of schoolchildren lumbar spine rotational mobility in the trial and control groups significantly differed. Therefore, if we compare the growth of investigated indicators in the period from 5th to 9th grades of the trial group (Δ%), the mean positive growth of the results is obvious by 11.57% to the right and 12.13% to the left in the boys; a similar tendency was noted in the girls. The regression of lumbar spine rotational mobility indicators is more expressed in the control groups; therefore, the results of the lumbar spine right rotation worsened by 11.52% and the left rotation by 12: 32% in the 9th grade compared with the 5th. In the boys, the worsening of indicators was found by 11.52% in the right and 12, 32% in the left rotation. The best results of the lumbar spine rotational mobility were recorded in the 7th grade: in the boys they constitute 23.64° for the right and 22.27° for the left rotation. These indicators are lower in the girls: 18.92° for the right and 19.37° for the left rotation. In the 9th grade, the significant differences were found between investigated indicators in the trial and control groups both in the boys and in the girls (correspondingly, t=2.29, $p<0.05$, t=2.92, $p<0.01$, and t=2.76, $p<0.01$, t=2.48, $p<0.05$).

This gives reason to assume that, on the one hand, the indicators of the spinal rotational mobility can serve to some extent as an indicator of the spinal cord functional condition, most sensitive and reacting to the decrease of its movements; on the other hand, we have shown the efficiency of the targeted use of special exercises aimed to improve the rotational movement of the spine in the process of a physical education lesson. It can be assumed that the efficiency of special exercises significantly rises with their daily performance. With regard to the solving of the assigned tasks, it is appropriate to mention the significance of such forms of knowledge in the school regimen, as morning gymnastics, exercise pauses etc., as well as the performance of special physical exercises as homework.

According to the generally accepted opinion of experts, the strength endurance of the muscles of the back and abdomen can be considered as a criterion for the stability of spine functioning [18]. Testing results of schoolchildren's back muscle endurance throughout the long-term study witnesses its regular growth with age (Table 4). Along with that, the character of the changes is controversial. Therefore, both in the girls and boys, from the 1st to 4th grades of the trial group, the growth of the speed of back muscle endurance indicators markedly exceeds those from the 5th to 9th grades. The collected data is explained by body weight and length growth discrepancy that leads to changes in its proportion on the one hand, and muscle mass growth on the other [19]. Comparing the results obtained from trial and control groups revealed a significant difference. E.g., in two age groups of the trial class, the girls' growth of back muscles endurance exceeds that recorded in the control groups. At the same time, it should be noted that the significant differences were found only among the boys of the 1st group (t=1.98, $p<0.05$).

Abdominal press muscles strength testing results witness their improvement in all the investigated classes; however, indicators growth, as expected, are higher in the trial groups. Along with that, it should be stated that strength indicators of abdominal press muscles, both in dynamic and in static regimens, are markedly below the norms for given age groups and are characterized as average and below average [1].

Table 4. The dynamics of the strength indicators of schoolchildren's back and abdominal press muscles in the longitudinal section (X ± m)

1st Group							
Indicators	**Groups**	**1st grade**	**2nd grade**	**3rd grade**	**4th grade**	**Δ**	**Δ%**
Boys							
Endurance of back muscle (t sec.)	**Trial**	41.75±9.65	51.46±9.82	65.45±10.8	90.18±12.40	48.43	116
	T %	-	23.26	27.19	37.78		
	Control	43.4±5.09	51.07±8.75	52.5±7.77	59.07±9.44	15.87	36.57
	T %	-	17.67	2.8	12.51		
45° angle (t sec.)	**Trial**	18.88±4.84	23.27±5.61	24.2±4.13	31.13±4.3	12.25	64.88
	T %	-	23.25	3.99	28.64		
	Control	19.55±5.93	20.6±5.2	21.45±5.4	22.2±5.65	2.65	13.55
	T %	-	5.37	4.13	3.49		
Leg rises (n times)	**Trial**	11.2±2.17	13.4±2.11	14.0±2.37	15.93±2.9	4.73	42.23
	T %	-	19.64	4.48	13.78		
	Control	10.6±2.14	12.2±1.85	13.86±2.09	15.4±2.14	4.8	45.28
	T %	-	15.09	13.61	11.11		
Girls							
Endurance of back muscle (t sec.)	**Trial**	23.27±4.67	37.46±6.24	47.71±12.03	58.45±11.28	35.18	151.18
	T %	-	60.98	27.36	22.51		
	Control	26.09±4.77	34.77±4.94	47.12±9.77	49.92±9.49	23.83	91.34
	T %	-	33.27	35.52	5.94		
45° angle (t sec.)	**Trial**	18.48±3.68	23.28±2.73	28.76±5.32	32.36±7.29	13.88	75.11
	T %	-	25.97	23.54	12.52		
	Control	17.37±4.37	22.09±3.23	23.23±3.36	23.54±3.46	6.17	35.52
	T %	-	27.17	5.16	1.33		
Leg rises (n times)	**Trial**	10.07±1.86	12.15±1.4	12.82±1.89	14.77±1.66	4.7	46.67
	T %	-	20.65	5.51	15.21		
	Control	10.92±1.59	12.12±1.85	12.27±1.88	13.07±1.82	2.15	19.69
	T %	-	10.99	1.23	6.52		

2nd Group								
Indicators	**Groups**	**5th grade**	**6th grade**	**7th grade**	**8th grade**	**9th grade**	**Δ**	**Δ%**
Boys								
Endurance of back muscle (t sec.)	**Trial**	66.4±11.62	74.33±9.06	81.27±15.62	81.8±22.31	86.66±12.4	20.26	30.5
	T %	-	11.94	9.34	0.65	5.94		
	Control	63.14±9.39	66.82±12.6	74.14±8.5	78.0±19.6	76.58±12.17	13.44	21.29
	T %		5.83	10. 95	5. 21	-1.82		
45° angle (t sec.)	**Trial**	14.11±5.23	19.0±4.57	24.78±6.6	32.2±5.84	42.58±5.12	28.47	201.8
	T %	-	34.65	30.42	29.94	32.24		
	Control	13.09±6.51	17.3±5.12	20.0±5.69	23.64±6.91	28.0±7.51	14.91	113.9
	T %	-	32.16	15.61	18.2	18.44		
Leg rises (n times)	**Trial**	12.82±3.32	16.27±3.42	20.2±6.29	22.33±4.74	24.6±4.86	11.78	91.89
	T %	-	26.91	24.15	10.54	10.16		
	Control	12.86±3.93	14.78±2.92	15.2±2.64	17.17±1.84	19.12±2.0	6.26	48.68
	T %	-	14.93	2.84	12.96	11.36		

Girls								
Endurance of back muscle (t sec.)	**Trial**	54.5±9.53	63.75±6.27	79.17±18.2	84.8±18.1	92.2±12.8	37.7	69.17
	T %	-	16.97	24.19	7.11	8.73		
	Control	52.78±11.04	58.5±9.26	65.37±10.8	68.5±11.4	78.67±14.24	25.89	49.05
	T %	-	10.84	11.74	4.79	14.85		
45° angle (t sec.)	**Trial**	17.12±2.89	25.5±6.5	28.83±9.9	33.6±6.54	37.13±6.9	20.01	116.88
	T %	-	48.95	13.06	16.54	10.5		
	Control	16.55±5.79	17.94±3.79	21.5±2.93	26.0±1.22	28.08±5.5	11.53	69.67
	T %	-	8.39	19.84	20.93	8.0		
Leg rises (n times)	**Trial**	12.56±1.48	16.13±1.93	18.67±2.05	20.89±2.5	21.5±2.93	8.94	71.18
	T %	-	28.42	15.75	11.89	2.92		
	Control	10.55±134	15.0±2.23	16.91±2.72	17.25±2.52	19.1±3.63	8.55	81.04
	T %	-	42.18	12.73	2.01	10.72		

Notes: (X±m) t – duration of pose preservation in seconds, n – number of exercise repetitions in "times", T – compound annual growth rate.

Discussion

A summary of the results obtained during the pedagogical trial reveals controversy surrounding spinal cord mobility changes with age. Along with the regular improvement of one indicator, the worsening of the others is noted. This tendency is revealed both in the boys and girls.

Thus, the results of the long-term pedagogical trial enabled us to reveal the features of spine mobility indicators at the stage of school ontogenesis. The collected data demonstrates abrupt and rapid changes of schoolchildren's spinal mobility indicators in different age stages. Many years of investigation of this has allowed us to underline a number of patterns, describing features of the spine functioning, as well as to reveal the critical periods of its ontogenesis.

The results of annual testing demonstrate a significant improvement of the spinal mobility indicators in frontal, sagittal planes, and the rotational mobility of lumber spine, both in the boys and girls of the trial groups. The positive dynamics in the right and left bends, back lean, and rotations are especially expressed.

Also, the general low forward lean results in all the age groups are unsatisfactory. Therefore, the mean highest results in forward lean were noted in the 9th grade girls: +4 cm, with age norm of +8-10 cm; in the boys of all the age groups, the mean results obtained were with a "minus" sign. It should be noted that this test, forward lean, has been recognized by experts as integral in human general flexibility assessment.

The results of the cervical spine rotational mobility, recorded in all the age groups, show that this part of the spine is the most vulnerable, sensible, and "fast-reacting" chain on its movement insufficiency. This confirms the need for special cervical spine "workout".

The data obtained in the control groups was of particular concern. The worsening of the results, that we found for a number of indicators (neck rotation, forward leans, and side bends) in the 9th grade, could demonstrate that both had probably started already at school age with regressive changes of the spine, because of its insufficient movement and the inefficiency of the physical education lesson in terms of the tasks we solve. The negative dynamics of the investigated indicators gives a reason to assume that the performance of special exercises to improve spinal mobility during physical education lessons only, with the decrease of movement activity volume of the high school students, is not able to counteract early signs of regression. Daily performance of special exercises is essential here, using different forms of the physical education organization in school day regimen and at home: exercises before classes and "exercise minutes".

Conclusions

This long-term pedagogical experiment has confirmed our assumption regarding the necessity to include in the school physical education lessons content including a specially developed complex of exercises aimed at improving spinal cord mobility. The testing results of experimental classes in all the age groups support this claim, where the investigated parameters notably improved. The special exercises that were tested, as well as methodological approaches in all the age groups, has allowed us to conclude that the spinal cord mobility should be improved, regardless of the age group, in accordance with basic didactic principles.

What is more, the data on spinal mobility derived from the control group have shown that at the stage of school ontogenesis, worsening is also possible. That gives us a reason to affirm that what is most valuable in the spinal mobility improvement are special techniques, such as a specially organized pedagogical program, and not features of the age development.

The testing results in the control groups show the regressive changes that have started already at the school age and the character of which can appear as different pathologies in adulthood.

Our investigations have confirmed the need for and the importance of developing physical education content focused on maintaining and improving the health of younger generation. In this regard, the special importance is also given to the development of comprehensive physical education and necessary movement skills, aimed at increasing the spinal mobility and providing its normal functioning.

Educational tasks, exercises to develop healthy spine, as well as theoretical material, which includes all the necessary information pertaining to this question, need to be included in the content of physical culture lessons throughout the school education.

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References:

1. Kashuba VA. [Biomechanics of the posture]. Kiev: Olympic Literature; 2003. p. 280 (in Russian).
2. Chelnokov VA. [Features of the interpretation of modern theory of spine osteochondrosis pathogenesis in sports medicine]. Theory and Practice of Physical Culture. 2004; 1: 12-15 (in Russian).
3. Sitel AB. [Solo for the spine]. Moscow: Metaphor; 2007. p. 224 (in Russian).
4. Kobisheva LI. [Contemporary state of the health preservation problem of schoolchildren in pedagogical science and education practice]. Child Trainer. 2008; 1: 4-12 (in Russian).
5. Spirin VK. [Children posture correction by physical culture taking into count congenital predisposition for speed work and endurance work performance]. Physical Culture: Upbringing, Education, Training. 2002; 2: 48-52 (in Russian).
6. Andrianov VP, Bairov GA, Sadofyeva VI, Raive RE. [Diseases and traumas of the spine in children and adolescents]. Leningrad: Medicine; 2008. p. 18-28 (in Russian).
7. Teksheva LM, Elksnina YV, Perminov MA. [Hygenical aspects of computer media use in the system of general education]. Hygiene and Sanitary. 2007; 4: 65-69 (in Russian).
8. Gheysvandi E, Dianat I, Heidarimoghadam R, Tapak L, Karimi-Shahanjarini A, Rezapur-Shahkolai F. Neck and shoulder pain among elementary school students: prevalence and its risk factors. BMC Public Health. 2019; 19: 1299. https://doi.org/10.1186/s12889-019-7706-0

9. Khvisyuk NI, Prodan AI, Pukhacheva SS, Dedukh NV, Timoshenko OP. [Spine osteochondrosis in children]. Kiev: Health; 1985. p. 104 (in Russian).
10. Rai A, Agarwal S. Assessing the effect of postural discomfort on school going children due to heavy backpacks. Ergonomics. 2014; S4 (011): 2-3. https://doi.org/10.4172/2165-7556.S4-011
11. Hossain FMA, Tonima Masuda A. A study on the effects of heavy backpack and development of a preventative prototype. Journal of Sensors. 2017; 10: 9419373. https://doi.org/10.1155/2017/9419373
12. Wildhe T. Spine: posture, mobility and pain. A longitudinal study from childhood to adolescence. Eur. Spine J. 2001; 10: 118-123. https://doi.org/10.1007/s005860000230
13. Lebedyanskaya LE. [Features of joint mobility (flexibility) development methods]. [Abstract of doctoral thesis]. Moscow; 1952. p. 15 (in Russian).
14. Hakobyan YS. [Human spine mobility: age aspect and improvement methods]. [Abstract of doctoral thesis]. Yerevan: Armenian State Pedagogical University after Khachatur Abovyan; 2015. p. 48 (in Russian).
15. Bohajar-Lax Á, Vaquero-Cristóbal R, Espejo-Antúnez L, López-Miñarro PÁ. [The effect of a hamstring streching protocol on hamstring extensibility in adolescent students: influence of the class session weekly distribution]. Nutr. Hosp J. 2015; 32: 1241-1245 (in Spanish).
16. Mayorga-Vega D, Merino-Marban R, Manzano-Lagunas J, Blanco H, Viciana J. Effects of a stretching development and maintenance program on hamstring extensibility in schoolchildren: A cluster-randomized controlled trial. J. Sports Sci. Med. 2016; 15: 65-74.
17. González-Gálvez N, Marcos-Pardo PJ, Trejo-Alfaro H, Vaquero-Cristóbal R. Effect of 9-month Pilates program on sagittal spinal curvatures and hamstring extensibility in adolescents: randomised controlled trial. Sci Rep J. 2020; 10: 9977. https://doi.org/10.1038/s41598-020-66641-2
18. Agayants EK, Berdichevskaya EM, Demidova EV. [Physiological features of children, adolescents and youth development]. Krasnodar: Krasnodar Institute of Physical Culture; 1999. p. 72 (in Russian).
19. Khripkova AG, Antropova MV, Farber DA. [Age physiology and school hygiene]. Moscow: Enlightenment; 1990. p. 319 (in Russian).