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Analysis of Cardiovascular and Respiratory System Functional Indicators in School Students in Andijan City, Republic of Uzbekistan

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Abstract The scientific research study analyzed the functional indicators of the cardiovascular and respiratory system in students (grades 1-11) from schools No. 1, No. 5, No. 6, No. 11, No. 13, No. 15, No. 24, No. 30, No. 31, and No. 48 located in Andijan City, Republic of Uzbekistan, during the years 2021-2022. Centile-scale values related to vital lung capacity (ml) and heart rate (beats per minute) for physiological age groups (7-17 years) have been developed for students. The average values of vital lung capacity in students show a dynamic increase in the range of 7-17 years (for boys: 1089±15.47 – 3070±12.53 ml; for girls: 1013±12.64 – 2810±14.68 ml). The average heart rate values are 91.71±5.20 – 80.22±5.02 bpm for boys, and 86.46±4.32 – 70.91±4.37 bpm for girls, indicating that the obtained results correspond to physiological norm values. The average values of the life index in the age range of 7-17 years are 49.84±1.05 – 52.63±0.33 ml/kg for boys and 47.13±1.18 – 53.61±0.50 ml/kg for girls. The spirometric indicators are accordingly 8.99±0.06 – 17.75±0.03 ml/cm for boys and 8.39±0.04 – 17.38±0.04 ml/cm for girls. The Skibinsky index values are respectively 206.61±3.14 – 720.76±6.01 and 178.02±4.35 – 681.80±3.21. The Ruffier index values are found to be 10.72±0.15 – 7.27±0.18 and 9.48±0.03 – 4.51±0.02, respectively. Based on these results, anthropo-physiological standards can be developed to optimize the physical development level of students in education, taking into account the physiological indicators of the organism during physical education classes, and aligning students' intellectual development during the learning process. This can serve as a scientific basis for developing practical measures based on an individualized approach strategy.

Keywords School students, Vital lung capacity, Heart rate, Life index, Spirometric indicators, Skibinsky index, Ruffier index

1. Relevance

In todays world, under the conditions of widespread implementation of innovative pedagogical technologies in the school education system, the physiological justification of the impact of workload on students physical and intellectual development is of urgent importance for optimizing the educational process [3].

The physical and mental well-being of the school student population is of significant importance in the structure of public health, and notable decline in this demographic has been observed in recent years [15-17].

The decline in students' health is significantly influenced by the increasing volume of intellectual workload in education, which indicates neuro-physiological strain [11].

Under the impact of modern intensive teaching technologies, there is a noticeable deterioration in students health, along with a rising trend in cardiovascular and other various illnesses [1].

In analyzing these changes, cardiovascular system indicators play a crucial role [4].

The functional indicators of the cardiorespiratory system in children and adolescents are highly sensitive to physical load, serving as important indicators of the level of adaptive capacity in the mechanisms that develop the organism's ability to adjust to external environmental conditions [7].

Thus, the physiological justification for coordinating the functional activity of the cardiorespiratory system is of urgent importance in developing strategies for optimizing the educational process [2].

2. Purpose and Objectives of the Research

The scientific research study analyzed the functional indicators of the cardiorespiratory system in students,

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including vital capacity of the lungs, heart rate, life index, spirometric indicators, Skibinsky index, and Ruffier index.

3. Research Methods

The scientific research study The research was conducted in 2021-2022 among students (grades 1-11) at schools No. 1, No. 5, No. 6, No. 11, No. 13, No. 15, No. 24, No. 30, No. 31, and No. 48 in Andijan, Uzbekistan (with 10 boys and 10 girls selected from each class).

Vital capacity of the lungs is a critical indicator for assessing the functional state of the respiratory system. It was measured using the "SSP spirometer" device ("Medapparatura," Ukraine) with three repetitions, recording the highest value. After 2-3 free breaths, a maximal deep breath was taken, and the spirometer tube was puffed into [6].

The functional capacity of the respiratory system in students was assessed using the **life index**, which was calculated with the following formula (1) to evaluate the state of compensatory-adaptive reactions [12]:

$$\textbf{\textit{Life Index = VC / BW}} \text{ (ml/kg)} \quad (1)$$

Here, *LI represents the life index (ml/kg), VC is the vital capacity of the lungs (ml), and BW is body weight (kg). (For example: if VC = 4,500 ml and BW = 78 kg, then LI = 4,500/78 = 57.7 ml/kg, which indicates that this value is "below average").*

The life index for adult men ranges from 65-70 ml/kg, while for women it is 55-60 ml/kg. For boys aged 5-6 years, the index is 49-53 ml/kg, and for girls, it is 40-47 ml/kg. At ages 7-10, the corresponding values are 51-55 ml/kg for boys and 45-49 ml/kg for girls. For ages 11-13, the values are 49-53 ml/kg for boys and 42-46 ml/kg for girls. For ages 14-15, the values are 53-57 ml/kg for boys and 46-51 ml/kg for girls. For ages 16-17, they are 55-63 ml/kg for boys and 48-55 ml/kg for girls. Higher values indicate a strong compensatory-adaptive reaction of the respiratory function, while lower values suggest dysfunctional changes in the compensatory-adaptive response of the respiratory system [7].

The spirometric indicator allows for the assessment of the functional capacity of the respiratory organs and is calculated using the following formula (2) [Artemenkov, 2022; pp. 55-517]:

$$\textbf{\textit{SI = VC / H}} \quad (2)$$

Here, *SI is the spirometric indicator (ml/cm), VC is the vital capacity of the lungs (l), and H is height (cm). In healthy individuals, the average value is 20 ml/cm for men and 17-18 ml/cm for women* [5].

Analyzing heart performance after physical load provides objective data on the physical development level of individuals, particularly students, with an average of 20 ml/cm for men and 17-18 ml/cm for women [10].

Heart rate is an adequate indicator for assessing the functional activity of the cardiovascular system and its adaptive capacity. In school students, it was measured in a seated position using a stethoscope ("Heaco 747"; Ukraine) (pulseometry) [14].

Analyzing the level of physical development in students and the express assessment of their health status through physiometric indices (Skibinsky index, Ruffier index, etc.) provides an opportunity to obtain objective data [11].

The cardiorespiratory system ensures the delivery of oxygen (O2) to tissues through circulating blood and the removal of carbon dioxide (CO2) as a byproduct of oxidation (respiration). The functional activity of the cardiorespiratory system was assessed using the **Skibinsky index** (SI), calculated with the following formula (3) [12]:

$$\textbf{\textit{SI = (VC × Stange test) / HR}} \quad (3)$$

Here, *SI represents the Skibinsky index (ml), VC is the vital capacity of the lungs (ml), Stange test is measured in seconds, and HR is the heart rate (beats per minute).*

The Skibinsky index allows for the joint assessment of the functional reserve capabilities of the cardiorespiratory system [9].

After providing a load to the students, the **Ruffier index** *("Physical Performance Index"* or Ruffier test) was calculated using the following formula (4) to assess the adaptation level of the cardiovascular system's functional activity [12]:

$$\textbf{\textit{Ruffier index =[4×(}}P_1+P_2+P_3\textbf{\textit{)–200]/10}} \quad (4)$$

After sitting quietly for 5 minutes, the *heart rate* (HR) is measured **for 15 seconds** (P_1). In the next phase, after standing up and sitting down 30 times for 45 seconds, the *HR* is again measured for 15 seconds while seated (P_2). Recovery is assessed by measuring the *HR* for 15 seconds during the last minute after resting (P_3).

The Ruffier index allows for the determination of the recovery level of heart rate under standard load conditions, providing an assessment of cardiovascular functional activity and adaptive reserves, rated as follows: <0 is *"excellent"*, 1-5.9 is *"good"*, 6-10.9 is *"satisfactory"*, 11-15 is *"weak"*, and >15 indicates "*unsatisfactory*" (*cardiovascular insufficiency*) [8].

The Ruffier index has been confirmed to provide objective data for the rapid assessment of the reserve capabilities of the cardiovascular system and adaptation dynamics in students under load conditions [17].

The experimental results were processed mathematically and statistically using software packages such as "Microsoft Excel 2007" (Microsoft, USA) and OriginPro v. 8.5 SR1 (EULA, USA) according to standard methods [3].

The experimental results are presented in the form $M \pm m$, where M is the mean arithmetic value and m is the standard error, based on n repetitions (n=3-4). The statistical significance of the differences between group values was calculated using *Student's t-test* ($p<0.05$ and $p<0.01$ were considered statistically significant) [13].

4. Results and Discussion

In scientific research, centile-scale values related to lung vital capacity (ml) and heart rate (beats/minute) were developed according to physiological age periods (7-17 years) for students. The average values of lung vital capacity increased dynamically within the range of 7-17 years (for boys: 1089±15.47 to 3070±12.53 ml; for girls: 1013±12.64 to 2810±14.68 ml). The average heart rate values were found to be 91.71±5.20 to 80.22±5.02 beats/minute for boys, and 86.46±4.32 to 70.91±4.37 beats/minute for girls, indicating that the results align with physiological norm values (Table 1a, 1b).

The average values of the life index in the 7-17 years range were 49.84±1.05 to 52.63±0.33 ml/kg for boys and 47.13±1.18 to 53.61±0.50 ml/kg for girls. The spirometric index was measured as 8.99±0.06 to 17.75±0.03 for boys and 8.39±0.04 to 17.38±0.04 for girls. The Skibinsky index values were found to be 206.61±3.14 to 720.76±6.01 for boys and 178.02±4.35 to 681.80±3.21 for girls. The Ruffier index was measured as 10.72±0.15 to 7.27±0.18 for boys and 9.48±0.03 to 4.51±0.02 for girls (Table 2).

The human body functions as a whole, relying on the coordinated activity of various organ systems, with the cardiorespiratory system playing a crucial role in the adaptation process within the educational environment [13].

In the educational setting, the dynamic characteristics of cardiorespiratory indicators, influenced by exogenous and endogenous factors, are emphasized in relation to physical and intellectual development [3].

The experimental results obtained generally align with the average values reported in studies conducted across the CIS [3].

In the context of the educational environment, analyzing the functional state of the respiratory system during students' intellectual performance allows for the identification of mechanisms for adapting to the influence of endogenous and exogenous factors throughout different age periods, as well as the laws associated with compensatory reactions [17].

During their education, students' thoracic and respiratory systems develop morpho-functionally, with respiratory indicators remaining significantly stable in conditions of intellectual performance [2].

The functional activity of the cardiorespiratory system develops rapidly in response to adaptation to the educational environment [5].

Table 1a. Centile-scale analysis of lung vital capacity (ml) and heart rate (beats/minute) among school students (7-17 years old), boys

Centile Values	**Age**	***min.-max.***	**Arithmetic Mean (*M*±*m*)**	**3**	**10**	**25**	**50 (Median)**	**75**	**90**	**97**
Interval				**I**	**II**	**III**	**IV**	**V**	**V**	**VII**
boys (♂ *n*=1 100)										
Lung Vital Capacity (ml)	7	600–1500	**1089±15,47**	700	800	900	**1100**	1200	1400	1500
	8	800–1600	**1110±13,51**	800	900	1000	**1100**	1200	1300	1500
	9	800–2000	**1318±24,17**	900	1000	1100	**1300**	1500	1600	2000
	10	900–2000	**1374±12,63**	1000	1100	1200	**1300**	1500	1800	2000
	11	1000–2600	**1796±10,37**	1200	1300	1500	**1800**	2000	2200	2500
	12	1000–2800	**1990±23,89**	1200	1400	1700	**2000**	2300	2500	2600
	13	1200–3000	**2220±11,74**	1500	1600	1900	**2300**	2500	2700	2800
	14	1200–3200	**2590±14,00**	1500	2000	2500	**2600**	2900	3000	3200
	15	2000–3600	**2790±17,32**	2200	2400	2500	**2700**	3000	3300	3500
	16	2200–3900	**3040±20,18**	2300	2500	2700	**3000**	3400	3600	3800
	17	2200–3900	**3070±12,53**	2400	2600	2800	**3000**	3500	3600	3800
Heart Rate (beats/minute)	7	75–110	**91,71±5,20**	79	84	88	**90**	96	100	106
	8	75-105	**90,21±4,86**	76	80	85	**90**	96	100	102
	9	70–106	**87,06±3,80**	74	77	80	**86**	93	100	102
	10	69–115	**85,59±4,40**	70	71	79	**86**	90	93	102
	11	69-108	**84,32±4,17**	70	75	79	**83**	88	96	104
	12	73–112	**83,03±3,15**	74	76	78	**81**	87	92	98
	13	70–110	**83,76±4,19**	72	74	77	**81**	90	96	102
	14	70–101	**82,83±3,27**	71	73	77	**82**	87	93	99
	15	66–104	**81,39±3,29**	69	70	74	**80**	88	94	98
	16	67–100	**80,88±4,36**	68	71	76	**91**	87	80	96
	17	68–96	**80,22±5,02**	69	71	76	**79**	86	90	93

Note: The 25-75 centile (III-V interval) is assessed as the standard (average).

Table 1b. Centile-scale analysis of lung vital capacity (ml) and heart rate (beats/minute) among school students (7-17 years old), Girl

Centile Values	Age	Min.-Max.	Arithmetic Mean (M±m)	3	10	25	50 (Median)	75	90	97
Interval				I	II	III	IV	V	V	VII
Girls (♀ *n*=1 100)										
Lung Vital Capacity (ml)	7	600–1400	**1013±12,64**	700	800	900	**1000**	1100	1200	1300
	8	700–1900	**1130±10,28**	800	900	1000	**1100**	1200	1400	1800
	9	900–2000	**1244±16,37**	900	1000	1100	**1200**	1300	1500	1800
	10	900-1900	**1289±20,14**	1000	1100	1100	**1200**	1400	1600	1700
	11	1000–2500	**1616±18,27**	1100	1200	1400	**1500**	1800	2000	2200
	12	1200–2900	**1960±22,65**	1200	1400	1600	**2000**	2200	2500	2800
	13	1200–3000	**2260±14,33**	1300	1800	2100	**2300**	2500	2600	2800
	14	1200–3000	**2480±15,88**	1500	2000	2400	**2500**	2600	2900	3000
	15	1200–3500	**2630±25,50**	1500	2100	2500	**2600**	2900	3000	3200
	16	2400–3500	**2810±16,15**	2400	2500	2600	**2800**	3000	3100	3400
	17	2200–3200	**2810±14,68**	2400	2500	2600	**2800**	3000	3100	3200
Heart Rate (beats/minute)	7	75–98	**86,46±4,32**	75	79	82	**88**	90	93	95
	8	69-95	**82,22±3,71**	70	76	78	**82**	86	90	92
	9	68-89	**80,91±5,43**	71	76	78	**80**	84	88	89
	10	66–90	**77,48±3,19**	70	71	74	**77**	80	84	87
	11	67–88	**76,56±4,46**	69	70	73	**76**	80	82	86
	12	67–86	**75,04±5,07**	68	70	71	**76**	78	80	84
	13	66–83	**73,53±3,86**	68	69	70	**73**	76	79	80
	14	65–81	**72,03±4,91**	66	67	70	**71**	75	77	78
	15	65–79	**71,88±5,10**	66	67	69	**71**	75	76	77
	16	66–79	**71,64±3,28**	66	68	69	**71**	74	76	77
	17	65–79	**70,91±4,37**	66	67	68	**70**	73	75	79

Note: The 25-75 centile (III-V interval) is assessed as the standard (average).

Under the influence of stress factors, dysfunctional changes in the regulatory mechanisms of the cardiorespiratory system can occur, such as increased arterial blood pressure and decreased lung capacity, which are reflected in changes in heart rate [1].

Changes in cardiovascular system activity are found to be dependent on physiological age periods, as well as the intensity of stress factors, with a broad spectrum of changes observed in physical versus intellectual performance [9].

Heart rate serves as an objective indicator of cardiovascular functional activity, reflecting the adaptive capabilities and dynamic regulation mechanisms of the organism in response to various influences [4].

The heart rate values obtained in the studies generally fall within the *"physiological norm"* range [16].

Changes in heart rate during intellectual and physical activities among students are believed to be related to a decline in the functional activity of the cardiovascular system's neuro-humoral regulation mechanisms under stress factors [7].

At the end of the academic year, a decrease in heart rate values among students is noted, indicating a decline in the functional capabilities of the cardiorespiratory system in adapting to the educational process [15].

Considering physiological age periods in the development of an individualized approach to optimizing academic loads in the educational process is crucial for preventing negative conditions. In particular, it is emphasized that the level of fatigue in students aged 13-14 is higher compared to those aged 7-8, increasing the likelihood of dysfunctional changes in the cardiorespiratory system [16].

5. Conclusions

Thus, the studies developed centile-scale values for lung vital capacity (ml) and heart rate (beats per minute) based on physiological age periods (7-17 years) among students. The average values for lung vital capacity showed a dynamic increase in the range of 7-17 years (in boys: 1089±15.47 – 3070±12.53 ml; in girls: 1013±12.64 – 2810±14.68 ml). The average heart rates were 91.71±5.20 – 80.22±5.02 bpm for boys and 86.46±4.32 – 70.91±4.37 bpm for girls, indicating that the results correspond to physiological norm values.

The average life index values in the range of 7-17 years were 49.84±1.05 – 52.63±0.33 ml/kg for boys and 47.13± 1.18 – 53.61±0.50 ml/kg for girls. The spirometric indicators were 8.99±0.06 – 17.75±0.03 ml/cm for boys and 8.39±0.04 – 17.38±0.04 ml/cm for girls. The Skibinsky index ranged

from 206.61±3.14 – 720.76±6.01 for boys and 178.02±4.35 – 681.80±3.21 for girls. The Rufye index was found to be 10.72±0.15 – 7.27±0.18 for boys and 9.48±0.03 – 4.51±0.02 for girls.

Table 2. Analysis of Cardiovascular and Respiratory System Functional Indicators Among School Students in Andijan City (7-17 Years Old)

№	Indicator	Physiological Age (Years)	Boys (♂ n=1 100)		Girls (♀ n=1 100)	
			min.–max.	Arithmetic Mean (*M±m*)	*min.–max.*	Arithmetic Mean (*M±m*)
1.	**Vital Index** *(ml/kg)*	7	25,75–73,11	**49,84±1,05**	23,32–73,11	**47,13±1,18**
		8	27,78–63,32	**43,19±0,08**	25,52–89,33	**45,90±0,09**
		9	27,23–84,51	**49,65±1,04**	26,73–75,90	**45,82±1,14**
		10	24,36–87,53	**45,38±0,30**	24,12–105,26	**43,33±0,25**
		11	24,67–90,21	**53,77±0,89**	26,67–88,35	**49,81±0,85**
		12	26,67–88,35	**49,81±1,03**	25,00–98,77	**54,78±0,24**
		13	30,77–82,33	**53,49±0,74**	27,03–85,32	**53,20±0,37**
		14	29,81–93,80	**57,97±0,47**	27,68–85,93	**54,31±0,75**
		15	35,34–86,66	**54,80±0,63**	25,48–81,19	**54,82±0,49**
		16	27,86–88,28	**55,53±0,30**	40,00–94,72	**57,02±0,35**
		17	27,35–69,10	**52,63±0,33**	31,04–77,79	**53,61±0,50**
2.	**Spirometric Index** *(ml/cm)*	7	5,88–12,30	**8,99±0,06**	5,21–11,76	**8,39±0,04**
		8	5,97–12,50	**8,69±0,05**	5,83–15,08	**8,91±0,06**
		9	6,40–16,00	**9,99±0,05**	6,52–14,84	**9,47±0,04**
		10	6,67–15,87	**9,92±0,03**	6,85–13,87	**9,30±0,05**
		11	7,14–18,98	**12,60±0,04**	6,76–16,54	**11,24±0,06**
		12	6,76–16,54	**11,24±0,04**	7,79–20,34	**13,47±0,05**
		13	8,70–20,98	**14,35±0,03**	7,23–18,63	**14,58±0,04**
		14	7,69–20,67	**16,05±0,05**	7,19–20,27	**15,76±0,04**
		15	11,49–22,58	**16,91±0,04**	8,00–21,08	**16,31±0,06**
		16	12,78–23,21	**17,85±0,04**	13,89–23,33	**17,54±0,05**
		17	12,72–22,67	**17,75±0,03**	12,79–21,05	**17,38±0,04**
3.	**Skibinsky Index** *(units)*	7	90,57–360,24	**206,61±3,14**	93,97–275,86	**178,02±4,35**
		8	118,10–317,13	**198,39±4,42**	131,25–364,94	**216,64±5,83**
		9	134,41–434,38	**253,67±4,02**	168,75–450,66	**253,78±4,16**
		10	160,87–482,88	**281,91±5,63**	188,51–425,00	**289,49±6,27**
		11	184,21–642,86	**385,37±6,44**	234,18–668,40	**381,97±5,29**
		12	234,18–668,40	**381,97±5,10**	267,86–803,57	**481,90±4,20**
		13	249,40–797,22	**517,90±5,00**	280,77–815,88	**600,14±4,18**
		14	303,90–900,00	**638,61±4,78**	357,86–923,91	**681,80±3,21**
		15	485,29–1092,86	**720,76±6,01**	321,43–968,33	**739,93±5,72**
		16	511,22–1269,03	**814,53±5,16**	615,58–1013,93	**788,30±4,69**
		17	553,20–1225,52	**837,99±4,19**	632,50–1006,06	**810,47±3,2**
4.	**Rufier Index** *(units)*	7	5,70–16,20	**10,72±0,15**	5,58–13,42	**9,48±0,03**
		8	5,13–15,18	**10,23±0,19**	3,53–12,40	**8,04±0,05**
		9	3,43–15,51	**9,17±0,12**	3,19–10,35	**7,59±0,04**
		10	3,12–18,53	**8,67±0,54**	2,51–10,69	**6,42±0,04**
		11	3,12–16,18	**8,25±0,71**	2,85–10,01	**6,11±0,03**
		12	2,85–10,01	**6,11±0,08**	2,85–9,33	**5,59±0,04**
		13	3,45–16,85	**8,06±0,27**	2,51–8,30	**5,07±0,03**
		14	3,45–13,84	**7,75±0,33**	2,17–7,62	**4,56±0,03**
		15	2,11–14,84	**7,27±0,18**	2,17–6,94	**4,51±0,02**
		16	2,45–13,50	**7,09±0,05**	2,51–6,94	**4,43±0,04**
		17	2,78–12,16	**6,88±3,13**	2,17–6,94	**4,18±0,04**

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