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Morphological and Functional Characteristics of 9- to 22-Year-Old Female Athletes Involved in Sports Aerobics

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Abstract—Parameters of physical development, the cardiorespiratory system, and physical fitness were studied in female athletes aged 9–22 years. It was found that sports aerobics affects profoundly the functional capacity of the muscular and cardiorespiratory systems and, to a smaller degree, the morphological characteristics of the body.

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Sports aerobics is an acyclic sport with complex, coordinated movements and athletic sequences, which originates from standard aerobics and includes elements of artistic and rhythmic gymnastics and acrobatics [1, 2]. The exercises in sports aerobics are like free exercises in gymnastics but are performed at a higher intensity and to dynamic music [3–5]. Children under 18 years of age are not admitted to world, European, or national championships. There are special children's competitions with simplified rules.

During competitions, athletes demonstrate a high level of cardiovascular performance and a mixed (aerobic and anaerobic) type of energy production [6, 7]. The resulting load is considered to be comparable to that in an 800-m race of similar duration accompanied by profound homeostatic changes. Specialists have distinguished motor skills such as coordination; dynamic, explosive, and static strength; flexibility; general endurance; vestibular balance; and agility as the factors most important for sports aerobics [8]. Most papers on sports aerobics focus on pedagogical aspects of training [1–4, 6, 8]. The influence of this sport on morphological and functional status is not clearly understood. Therefore, it is impossible to objectively estimate the effect of aerobic exercises on the body, individualize the load, and reveal the abilities of athletes.

METHODS

The study involved 93 female athletes aged 9–22 years who were trained for 2–10 years in sports aerobics. They were divided into five age groups: 9–10, 11–12, 13–15, 16–18, and 19–22 years. The training load (12–18 h per week) depended on age. The control group included 63 schoolgirls and female students undergoing standard exercise training (2 h per week). The main anthropometric parameters of physical development included body height, body weight, and chest circumference and were measured according to standard methods; Quetelet's index was also calculated [9]. The degree of pubescence was evaluated according to [10, 11] and somatotype was estimated according to the Heath–Carter protocol [12]. The main hemodynamic parameters were measured at relative rest, during a standard workload of 12 (kg m)/(min kg), and during a 3-min recovery. The heart rate (HR) was measured using a Polar S 120 heart rate monitor, the blood pressure (BP) was measured according to Korotkoff's method, and Kerdo's index was calculated. Stroke volume (SV) was calculated in the female athletes above 16 years according to Starr's formula [13] and in the athletes aged 9–15 years according to the modified formula of Pugina and Bomazh [14].

Cardiovascular adaptation to physical activity and the work capacity were studied using the ergometric step test. The absolute and relative parameters of aerobic productivity and physical work capacity (PWC_{170}) and the rate of recovery (recovery index, RI) were determined according to [15]. For a standard workload, the cardiovascular efficiency was assessed by chronotropic response to the exercise, cardiac output (CO) per unit PWC_{170} (CO/PWC_{170}/kg) [16], and the double product of the HR and systolic BP [17]. The vital lung capacity (VLC), the vital index, and the maximum inspiratory (IFR) and expiratory (EFR) flow rates were used as estimates for external respiration [18].

The physical fitness assessment included the following components: maximum number of push-ups, maximum time of holding legs in the L position, standing long jump, bends on a bench, and the muscle strength of wrist flexors and dorsal extensors. The sprinter or stayer type of adaptive responses was determined from the ratio of maximum muscle strength to maximum muscle endurance of the wrist [19–21].

Statistical analysis was performed using Student's t-test.

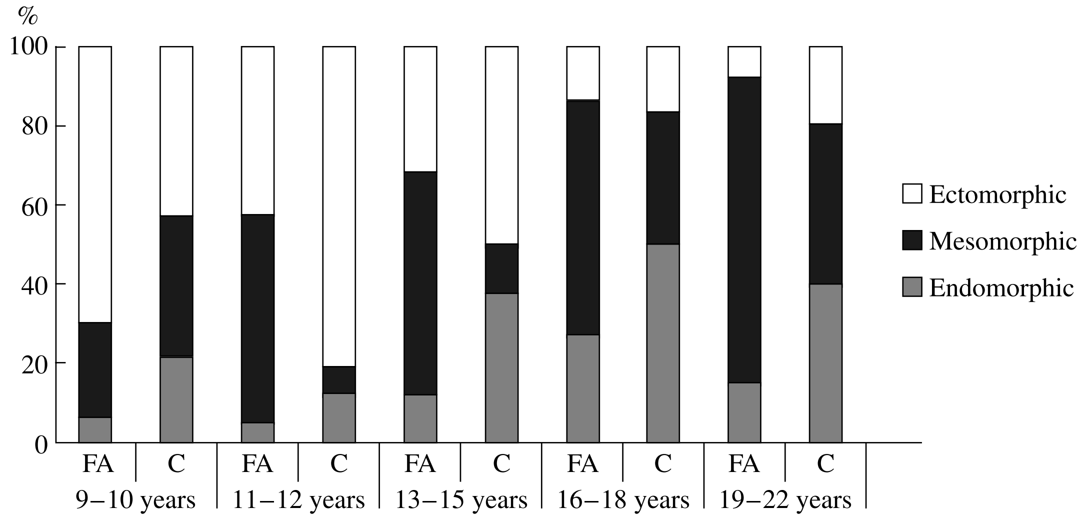

Fig. 1. Age-related distribution of subjects by somatotype (according to the Heath–Carter protocol). FA, female athletes involved in sports aerobics; C, controls.

RESULTS AND DISCUSSION

The anthropometric parameters of physical development and body fat in the female athletes did not differ considerably from those of the controls in most age groups. When compared to the controls, the female athletes displayed lower endomorphy from the age of 9 years, the differences being significant from the age of 16 years, and higher mesomorphy in most age groups (Table 1). The amount of and changes in the fat component during training is one of the main criteria of morphological typology of athletes [22, 23]. Analysis of somatotypes revealed that the portion of the female athletes with mesomorphic somatotype increased with age (Fig. 1). According to the findings, the degree of pubescence in the female athletes was lower than that in the control group (Table 1). In contrast to artistic gymnastics [24, 25], this difference was insignificant in all age groups and may be explained by a lack of sports selection, lower loads, and/or the absence of strict food restrictions.

From the age of 11 years, the female athletes involved in sports aerobics demonstrated significantly higher parameters of PWC_{170} and significantly more efficient blood circulation per unit PCW_{170} ($CO/PWC_{170}/kg$) (Table 2). The maximum oxygen consumption was higher in the female athletes (the differences were significant from the age of 13 years). They also had a higher RI from the age of 16 years. The data on the age-related changes in Kerdo's index, which reflected increasing influence of the parasympathetic nervous system, indicated cardiovascular efficiency in the female athletes. These differences became significant from the age of 16 years (Table 2). The chronoinotropic parameter, which characterized the total physiological cost of the standard physical load, was significantly lower only in the female athletes aged 19–22 years (Table 2).

Analysis of the respiratory function revealed that the VLC was virtually unchanged and the vital index was significantly higher only in the female athletes from the oldest age group. A static load or a load with static elements or straining efforts caused fewer shifts in all autonomic systems, including the respiratory system [26]. With extended training, the inspiratory volume increases considerably as compared to the expiratory volume, indicating a great strength of inspiratory muscles [18]. Only in the female athletes aged 19–22 years was the IFR close to the EFR; the forced EFR prevailed in the other age groups and in the controls (Table 2).

Analysis of the stayer or sprinter type of functional constitution revealed that the number of stayers decreased with age, the number of the mixed type increased, and the greatest percent of sprinters appeared among the female athletes aged 19–22 years (Fig. 2). The presence of sprinters in this age group is probably evidence for sports selection of the given type.

From the data presented, we can conclude that the differences in morphofunctional status between the female athletes involved in sports aerobics and the controls are the greatest at the age of 19–22 years. In this age group, high-caliber female athletes (four world-class athletes, five masters of sport, and four candidates of sport) were examined.

In all age groups, the female athletes had higher fitness levels and demonstrated significantly higher results ($P < 0.001$) in exercises for dynamic and static strength and flexibility. In addition, the female athletes demonstrated significantly higher results in the long jump (explosive strength) ($P < 0.05$). Note that the female athletes aged 9–10 years with higher initial fitness levels keep these advantages in the future. However, analysis of the handgrip and trunk strengths revealed no apparent differences between the groups (Table 1). This can be explained by a lack of coaches'

Table 1. Parameters of physical development and fitness in the female athletes (FA) involved in sports aerobics and in the controls (C) ($M \pm m$)

Parameter	Age group									
	9–10 years		11–12 years		13–15 years		16–18 years		19–22 years	
	FA (14)	C (13)	FA (21)	C (12)	FA (21)	C (13)	FA (22)	C (13)	FA (13)	C (12)
Body height, cm	139.6 ± 1.6	136.2 ± 1.3	149.7 ± 1.4	153.6 ± 1.6	159.6 ± 1.1	161.3 ± 1.4	162.5 ± 1.0	161.0 ± 0.9	161.2 ± 1.0	162.9 ± 1.2
Body weight, kg	31.6 ± 0.8	30.2 ± 0.9	38.0 ± 1.1	40.3 ± 2.2	47.9 ± 1.1	51.6 ± 2.3	54.7 ± 0.8	52.6 ± 1.1	54.6 ± 2.21	54.0 ± 1.9
Quetelet's index, kg/m^2	16.16 ± 0.24	16.28 ± 0.42	16.89 ± 0.27	17.02 ± 0.63	18.77 ± 0.37	19.81 ± 0.66	20.71 ± 0.36	20.29 ± 0.30	21.00 ± 0.36	20.44 ± 1.01
Chest circumference, cm	67.04 ± 0.94	65.96 ± 1.50	72.79 ± 0.90	74.25 ± 1.50	79.45 ± 1.21	81.08 ± 1.13	84.75 ± 0.59	84.00 ± 1.08	86.08 ± 0.75	85.17 ± 1.77
Endomorphy	2.57 ± 0.16	3.08 ± 0.21	2.81 ± 0.14	3.08 ± 0.35	3.52 ± 0.14	3.96 ± 0.38	4.09 ± 0.22	5.00 ± 0.25*	3.65 ± 0.21	4.92 ± 0.18*
Mesomorphy	3.75 ± 0.13	3.68 ± 0.12	3.76 ± 0.11*	3.26 ± 0.09	4.01 ± 0.16*	3.49 ± 0.13	4.32 ± 0.16	3.94 ± 0.2	4.30 ± 0.16	4.60 ± 0.26
Ectomorphy	3.79 ± 0.16	3.58 ± 0.38	4.05 ± 0.20	4.42 ± 0.40	3.67 ± 0.17	3.31 ± 0.38	2.77 ± 0.22	2.88 ± 0.13	2.42 ± 0.21	3.21 ± 0.40
Puberty, score	0.21 ± 0.12	0.32 ± 0.13	1.56 ± 0.18	2.58 ± 0.71	6.98 ± 0.68	7.07 ± 0.70	11.30 ± 0.21	11.46 ± 0.29	1.93 ± 0.43	12.30 ± 0.32
Number of push-ups	34.4 ± 3.3*	10.7 ± 1.6	29.3 ± 3.1*	15.8 ± 3.6	28.1 ± 2.5*	6.6 ± 1.5	26.6 ± 3.0*	12.2 ± 1.8	33.1 ± 1.9*	14.8 ± 1.6
L position, s	23.5 ± 3.0*	0.8 ± 0.4	22.0 ± 2.1*	3.8 ± 1.7	20.2 ± 2.3*	1.7 ± 1.0	20.0 ± 2.3*	0.4 ± 0.4	33.2 ± 4.8*	0.4 ± 0.3
Standing long jump, cm	147.3 ± 4.4*	127.2 ± 5.8	168.1 ± 2.7*	157.3 ± 4.3	178.7 ± 3.6*	152.2 ± 4.3	185.4 ± 4.7*	160.5 ± 5.7	186.4 ± 2.3*	165.8 ± 7.2
Bend, cm	15.9 ± 1.5*	6.4 ± 1.3	17.7 ± 1.0*	9.0 ± 1.7	21.2 ± 1.8*	10.6 ± 1.9	22.8 ± 0.9*	14.3 ± 1.8	26.5 ± 0.9*	11.2 ± 2.86
Handgrip dynamometry (right + left), kg	29.0 ± 1.2	26.1 ± 1.4	37.3 ± 1.7	37.5 ± 2.6	48.7 ± 1.9	46.5 ± 2.3	54.5 ± 1.5	50.5 ± 1.7	55.5 ± 1.8	58.4 ± 3.3
Trunk strength, kg	38.9 ± 2.7	36.5 ± 1.7	47.6 ± 2.3	41.0 ± 3.4	52.0 ± 2.3	56.9 ± 2.3	71.7 ± 3.2	66.2 ± 2.5	75.7 ± 2.8	72.3 ± 1.7

* Differences between the female athletes and the controls were significant at $P < 0.05$.

Table 2. Parameters of the cardiorespiratory system in the female athletes (FA) involved in sports aerobics and in the controls (C) ($M \pm m$)

Parameter	Age group									
	9–10 years		11–12 years		13–15 years		16–18 years		19–22 years	
	FA (13)	C (12)	FA (13)	C (12)	FA (13)	C (12)	FA (13)	C (12)	FA (13)	C (10)
PWC_{170}/kg, kg m/min kg	11.58 ± 0.29	11.33 ± 0.62	12.39 ± 0.37*	11.39 ± 0.33	11.65 ± 0.23*	10.35 ± 0.20	11.88 ± 0.24*	11.17 ± 0.22	14.46 ± 0.65*	10.41 ± 0.42
CO/PWC_{170}/kg, l kg/kg m	0.39 ± 0.02	0.46 ± 0.06	0.38 ± 0.01	0.43 ± 0.02*	0.42 ± 0.01	0.49 ± 0.03*	0.53 ± 0.02	0.60 ± 0.03*	0.49 ± 0.02	0.78 ± 0.06*
MOC/kg, ml/min/kg	43.40 ± 1.12	42.38 ± 1.40	43.15 ± 0.81	41.25 ± 1.15	39.6 ± 0.52*	36.50 ± 1.16	39.50 ± 0.89*	37.09 ± 0.75	49.44 ± 2.79	34.81 ± 0.83
RI, arb. units	5.82 ± 0.27	5.24 ± 0.21	6.86 ± 0.24	7.05 ± 0.41	8.57 ± 0.27	8.44 ± 0.47	10.04 ± 0.32*	9.28 ± 0.21	12.42 ± 0.47*	8.76 ± 0.54
Kerdo's index, arb. units	30.0 ± 2.8	32.8 ± 5.0	21.9 ± 2.1	27.2 ± 2.0	11.9 ± 2.9	19.1 ± 2.9	10.5 ± 2.6	24.3 ± 2.2*	5.31 ± 2.72	25.53 ± 4.01*
Double product (load), arb. units	206.4 ± 5.4	201.5 ± 5.3	210.5 ± 7.5	215.9 ± 7.7	232.1 ± 7.2	253.9 ± 10.9	236.9 ± 7.7	233.4 ± 8.6	197.23 ± 56.25	249.43 ± 3.29*
VLC, l	1.93 ± 0.05	1.78 ± 0.06	2.42 ± 0.09	2.46 ± 0.09	2.95 ± 0.08	3.14 ± 0.12	3.38 ± 0.09	3.12 ± 0.10	3.57 ± 0.09	3.26 ± 0.15
Vital index, ml/kg	61.2 ± 1.5	59.7 ± 3.1	63.7 ± 1.3	62.2 ± 2.9	61.8 ± 1.7	61.7 ± 2.6	61.6 ± 1.1	59.3 ± 2.0	65.44 ± 1.19*	60.39 ± 1.76
Maximum IFR, l/s	2.22 ± 0.14	1.88 ± 0.11	2.61 ± 0.16	2.76 ± 0.18	3.36 ± 0.16	3.30 ± 0.19	3.78 ± 0.15	3.43 ± 0.25	4.01 ± 0.17	3.94 ± 0.25
Maximum EFR, l/s	2.34 ± 0.07	2.39 ± 0.08	2.98 ± 0.15	3.34 ± 0.20	3.66 ± 0.13	3.95 ± 0.13	4.15 ± 0.13	4.13 ± 0.18	4.06 ± 0.21	4.46 ± 0.16

Notes: See text for abbreviations.
* Differences between the female athletes and the controls were significant at $P < 0.05$.

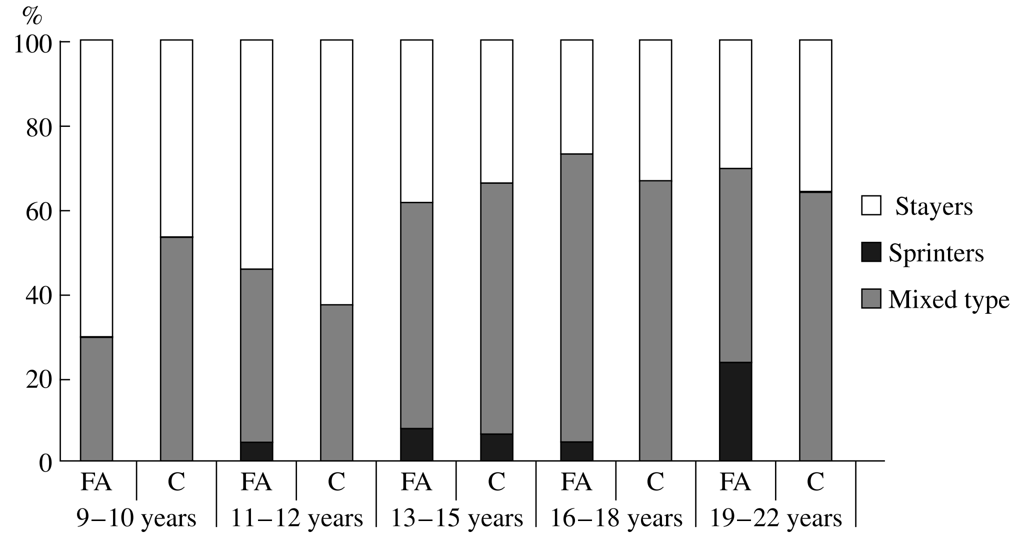

Fig. 2. Age-related distribution of subjects according to the sprinter or stayer type of functional reactions. See Fig. 1 for designations.

attention to balanced development of the strength of different muscle groups.

CONCLUSIONS

(1) The morphological characteristics whose improvement is promoted by sports aerobics become more pronounced with age and higher ranking and are associated with greater mesomorphic and smaller endomorphic components of the somatotype.

(2) Sports aerobics has a profound influence on the cardiovascular function, leading to an increase in physical work capacity, maximum oxygen consumption, and circulatory efficiency; higher adaptive capacity to physical load; and better recovery after exertion as compared with nonathletic subjects.

(3) The female athletes had higher fitness levels and demonstrated better results in exercises typical of sports aerobics as compared with subjects of the control group, which reflects the specific character of their training.

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