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CHANGES IN BODY COMPOSITION AND FUNCTIONAL DEVELOPMENT DURING PUBERTY

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Except for very early periods of life, at no other time of ontogeny is growth rapid as during puberty. This is most apparent during certain phases characterised by the peak height velocity. Nevertheless, the different systems and tissues do not develop at the same pace, which equally concerns morphological characteristics (including lean body mass and depot fat), indicators of functional development (vegetative system) and motorics. All this appears e. g. in the changes in the proportionality of the body, as well as in functional capacity and motor performance. In this respect there also exist marked sexual differences, wide inter-individual variability and an increased sensitivity to various environmental factors.

As described by various authors, acceleration of growth is most conspicuous during puberty when high values of different bodily dimensions are achieved by the prevailing proportion of adolescents. This situation is usually supposed to be a rather positive manifestation of generally improved conditions of life (including nutrition, health care, hygiene and no necessity for hard work during earlier periods of life). Data on the acceleration of growth are accessible especially as regards height and weight, as well as some further somatic parameters, as chest circumference, etc. There are very few data at disposal on body composition or changes in functional development over longer periods of time. Similarly, a considerable lack of data is felt on mutual relationships between morphological, functional and motor development during growth including puberty.

As regards somatic development, together with height and weight acceleration, marked changes in body composition (lean body mass and depot fat) occur; puberty in man is, namely, not the awakening of dormant glands, but a change in the level of activity of an already actively functioning network; sexual differences in fat and lean body mass, having already been apparant since birth, merely come to be manifested more markedly. The thickness of the suprailiac skinfold is significantly greater in newborn girls (PAŘÍZKOVÁ 1963, 1968). The proportion of fat, ascertained by densitometry (PAŘÍZKOVÁ 1959, 1961) is already significantly higher in girls of younger school age (in which we could start to use this method – PAŘÍZKOVÁ 1974, 1976). The difference between sexes is relatively greater immediately after puberty, even though the proportion of lean body mass is at all times significantly higher in males, even in advanced age. This is most apparent when we express the values of body fat in the females in the percentage of that in the males (equalling thus 100% – PAŘÍZKOVÁ 1963). In males, the proportion of lean body mass attains its peak around 20 years of age, which also corresponds to the peak of the absolute values of the aerobic capacity of the organism expressed by maximum oxygen uptake. This was described e.g. by ÅSTRAND and RODAHL (1970) who for this age-group gave the highest values of 4.110 l (± 0.06) of oxygen with males and of 2.900 l (± 0.04) of oxygen with females. Similar trends of ontogenetical changes are displayed by the muscular strength, motor perform-ance, etc. in the normal population (ÅSTRAND and RODAHL 1970, NORRIS and SHOCK 1960).

When we evaluate various parameters as related to total or lean body mass, the picture is somewhat different. A comparison of the aerobic capacity related to total body weight in different age-groups gave highest values already at the age of 14—15 years (PAŘÍZKOVÁ et al. 1972). This finding confirmed the previous conclusions of ÅSTRAND (1970) and others (CERETELLI et al. 1963). When the values of maximum oxygen uptake are expressed in relation to lean body mass, the results are the same (PAŘÍZKOVÁ 1975, PAŘÍZKOVÁ et al. 1972). This means that the highest level of aerobic progesses in the human body is attained as early as at the end of puberty.

A longitudinal study can reveal the characteristic changes of somatic etc. development in greater detail. In a group of 40 boys body composition was followed by densitometry from 10.7 to 17.7 years (Table 1). The results of this study showed characteristic variations in the absolute and relative values of lean body mass and depot fat during this period of growth, confirming the conclusions on the development of lean body mass from cross-sectional

Table 1

Changes of calendar and bone age, height, weight and body composition in individual years in adolescent boys followed during eight years ($n = 40$)

1. táblázat A naptári életkor, a csontéletkor, a testmagasság, a testsúly és a testösszetétel változásai a serdülő fiúknál az egyedi években, nyolc éven át nyomon követve ($n = 41$)

Individual years: *Egyedi évek:*		1	2	3	4	5	6	7	8
Calendar age (years) *Naptári életkor (év)*	$\bar{x}$ SD	10.65 0.40	11.67 0.45	12.68 0.40	13.75 0.42	14.65 0.39	15.65 0.37	16.61 0.69	17.73 0.36
Bone age (years) *Csontéletkor (év)*	$\bar{x}$ SD	10.88 0.84	11.90 0.89	12.89 0.73	13.73 0.78	14.79 0.98	16.04 1.34	17.23 1.23	18.17 1.08
Height (cm) *Testmagasság (cm)*	$\bar{x}$ SD	144.3 4.9	149.5 5.2	155.1 6.1	162.6 7.4	169.5 7.0	175.1 5.8	177.8 5.6	179.2 5.4
Weight (kg) *Testsúly (kg)*	$\bar{x}$ SD	35.98 4.09	39.55 4.51	43.92 5.72	50.27 7.44	57.11 8.27	63.35 7.46	65.03 8.24	69.57 6.12
Lean body mass (kg) *Sovány testtömeg (kg)*	$\bar{x}$ SD	29.73 4.77	33.38 3.78	37.50 4.82	44.42 6.44	50.03 7.94	54.96 6.70	59.63 6.00	63.56 5.85
Fat (%) *Zsír (%)*	$\bar{x}$ SD	17.3 5.4	15.6 7.1	14.6 5.9	11.6 5.4	12.4 4.7	13.2 5.3	8.3 4.1	8.6 4.9

studies (PAŘÍZKOVÁ 1959, 1963, 1968a, 1973/1976), also aerobic capacity, i. e. maximum oxygen uptake ascertained during graded work-load on a horizontal tread mill (ŠPRYNAROVA 1974, PAŘÍZKOVÁ and ŠPRYNAROVA 1968, 1970); the latter corresponded approximately to the results of cross-sectional comparisons (ÅSTRAND and RODAHL 1970, CERETELLI et al. 1963). In the same

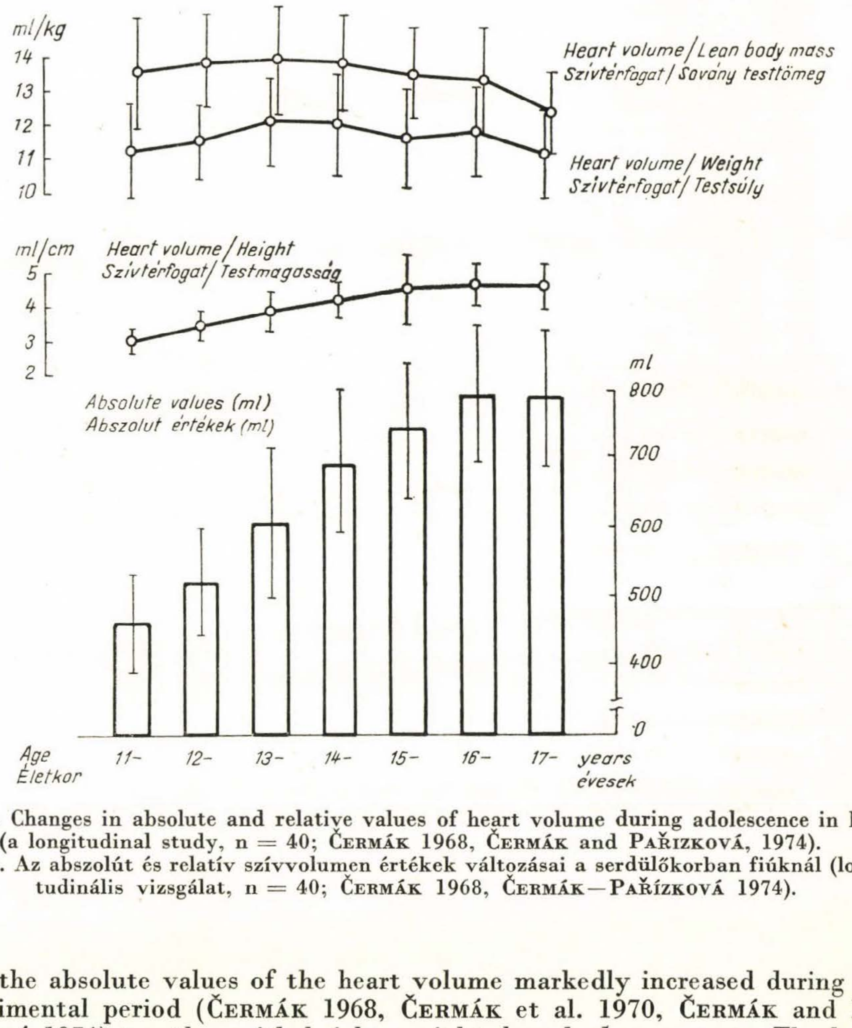


Fig. 1. Changes in absolute and relative values of heart volume during adolescence in boys (a longitudinal study, n = 40; ČERMÁK 1968, ČERMÁK and PAŘIZKOVÁ, 1974).
1. ábra. Az abszolút és relatív szívvolumen értékek változásai a serdülőkorban fiúknál (longitudinális vizsgálat, n = 40; ČERMÁK 1968, ČERMÁK—PAŘÍZKOVÁ 1974).

boys the absolute values of the heart volume markedly increased during the experimental period (ČERMÁK 1968, ČERMÁK et al. 1970, ČERMÁK and PAŘÍZKOVÁ 1974) together with height, weight, lean body mass, etc. The heart volume was determined by teleroentgenography in a supine position and on the left hip in antero-posterior and side projection during inspiration (MUSSHOFF and REINDELL 1965, ČERMÁK 1968). Heart volume was calculated according to ***Rohrer***'s formula as modified by MUSSHOFF and REINDELL (1965). At the age of 17 years, the increase of heart volume approximately levelled up (Fig. 1) and did not increase significantly in the last year. The evaluation of heart volume as related to body height followed a similar trend. When related to body weight (i. e. the heart quotient of KAHLSTORFF 1932), the peak appeared sooner, i. e. already at the age of 14 years. From the second to the fifth year of the experiment heart volume displayed relatively the same increase as lean body mass and, therefore, the relative heart volume/kg lean mass

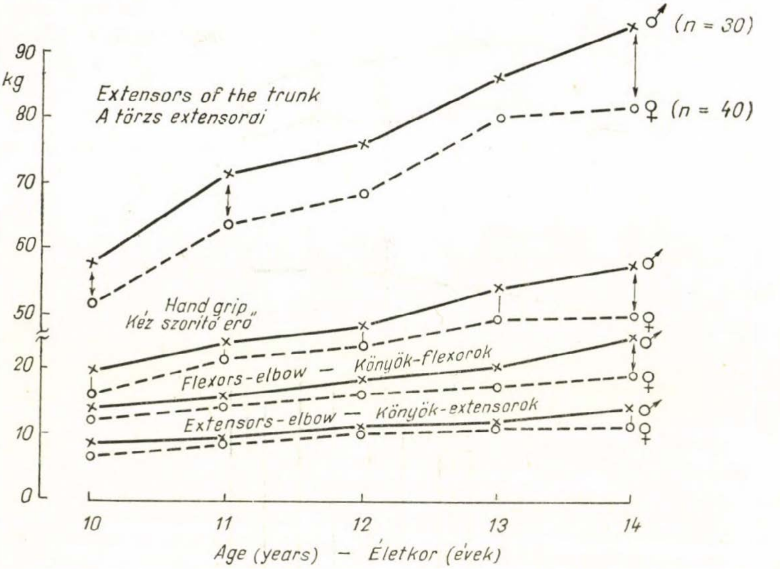
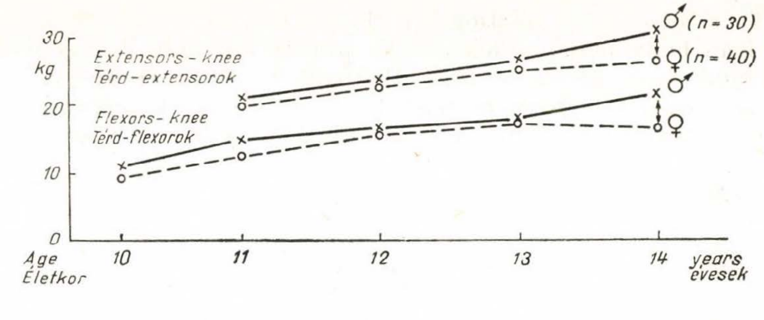


Fig. 2. Changes in muscle strength in boys and girls from 10 to 14 years (a longitudinal study, JUŘINOVÁ 1968).

2. ábra. Az izomerő változásai fiúknál és lányoknál a 10 és 14 év között (longitudinális vizsgálat, JUŘINOVÁ (1968).

did not change significantly during the said period, but decreased significantly during the last years (Fig. 1) (ČERMÁK and PAŘÍZKOVÁ 1974). The results of these evaluations correspond also to the conclusions on the aerobic capacity of the body. This is logical in view of the fact that the heart volume is proportional to the size of the oxidized tissues.

During puberty, motor performance in different disciplines, muscle strength, etc. markedly improve in boys, but level up or even decrease in girls, especially when the mentioned parameters are expressed as a function of total body mass. This was shown e.g. by ESPENSCHADE (1960), MALINA (1974) and others in cross-sectional comparisons. JUŘINOVÁ (1968) analysed the changes in the strength of different muscle groups by means of the dynamometer on the tensometric principle (JOACHIMSTHALER et al. 1961) in boys and girls from 10 to 14 years longitudinally (Figures 2. and 3). From the age of 12—13 years on, muscle strength did not develop along the same trend in girls as in boys, especially if expressed in relation to body weight and lean body mass (Fig. 3). Sexual differences were already apparent from 10 years on.



		10	11	12	13	14
Height (cm) Testmagasság (cm)	♂	141,1 (±4,9)	146,5 (±5,6)	152,0 (±6,4)	158,4 (±7,8)	165,6 (±7,4)
	♀	142,2 (±6,3)	148,8 (±6,4)	154,8 (±5,9)	159,7 (±5,8)	160,8 (±5,0)
Weight (kg) Testsúly (kg)	♂	33,83 (±4,77)	38,22 (±5,59)	42,17 (±6,51)	46,63 (±6,98)	52,68 (±7,67)
	♀	34,02 (±6,12)	38,94 (±7,92)	43,55 (±7,24)	48,35 (±7,37)	51,65 (±7,80)
Fat (%) Zsír (%)	♂	–	–	22,7 (±3,8)	18,9 (±4,9)	18,2 (±4,2)
	♀	–	–	24,0 (±3,9)	21,8 (±4,6)	22,0 (±4,5)
Total strength (per kg weight) Összerő/testsúly kg	♂	3,75	4,60	4,60	4,78	4,88
	♀	3,32	4,09	4,18	4,28	4,11
Total strength (per kg LBM) Összerő/sovány testtömeg kg	♂	–	–	5,95	5,89	5,97
	♀	–	–	5,50	5,48	5,27

Fig. 3. Changes in muscle strength, height, weight, body composition and relative strength in boys and girsl from 10 to 14 years (longitudinal study, JUŘINOVÁ 1968).

3. ábra. Az izomerő, a testmagasság, a testsúly, a testösszetétel és a relatív erő változásai fiúknál és leányoknál a 10 és 14 év között (longitudinalis vizsgálat, JUŘINOVÁ 1968).

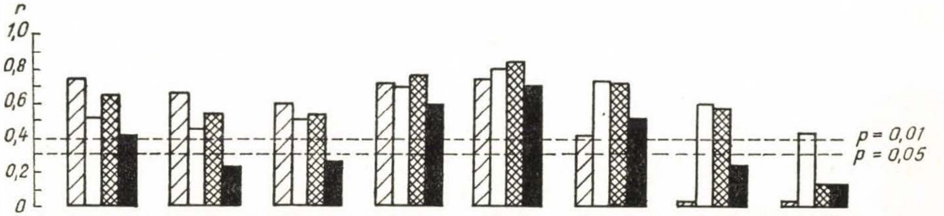


Fig. 4. Changes in the relationships (*r*) between bone age and height (hatched columns), bone age and weight (white columns), bone age and lean body mass (cross-hatched columns), bone age and heart volume (black columns) in boys from 10.7 to 17.7 years (a longitudinal study, n = 40; PAŘÍZKOVÁ 1976, PAŘÍZKOVÁ and ČERMÁK in press).

4. ábra. A csontéletkor és a testmagasság (ferdén satirozott oszlopok), a csontéletkor és a testsúly (fehér oszlopok), a csontéletkor és a sovány testömeg (kétszeresen satirozott oszlopok), a csontéletkor és a szívtérfogat (fekete oszlopok) közötti viszony (*r*) változásai fiúknál a 10,7 és 17,7 év között (longitudinális vizsgálat, n = 40; PAŘÍZKOVÁ 1976, PAŘÍZKOVÁ és ČERMÁK megjelenés alatt).

There exist close relationships between muscle strength and total, as well as lean body mass, which can be proved not only during puberty but also in adult and advanced age (PAŘÍZKOVÁ 1976). However, during puberty these parameters were measured without an exact evaluation of the degree of sexual maturation. In our longitudinal study the bone age (roentgenography

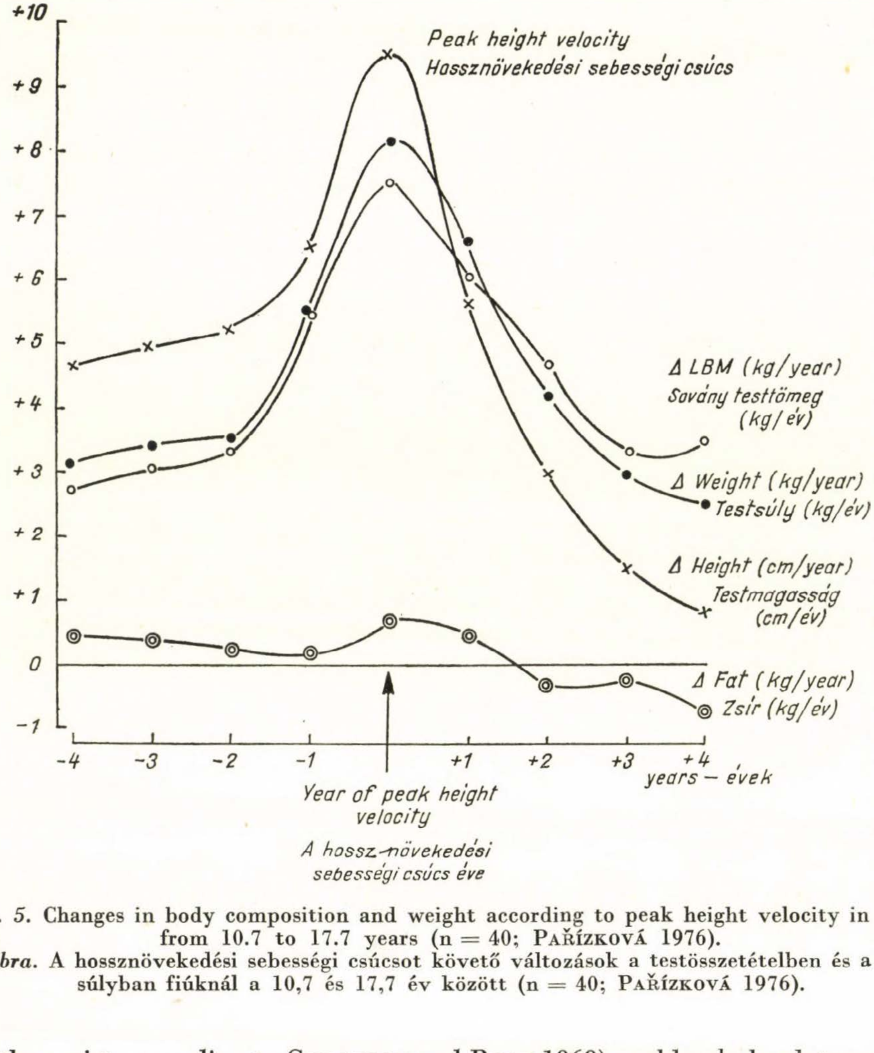


Fig. 5. Changes in body composition and weight according to peak height velocity in boys from 10.7 to 17.7 years (n = 40; PAŘÍZKOVÁ 1976).
5. ábra. A hossznövekedési sebességi csúcsot követő változások a testösszetételben és a testsúlyban fiúknál a 10,7 és 17,7 év között (n = 40; PAŘÍZKOVÁ 1976).

of the wrist according to GREULICH and PYLE 1969) could only be determined together with the measurements concerning somatic and functional development. A fair correlation between bone age and lean body mass, as well as between total body weight, height, heart volume and bone age was shown in boys in the individual years (1961—68) (Fig. 4). The maturation of the organism was paralleled by the increase in lean body mass and other parameters. The relationships changed during adolescence and disappeared after the 17th year except for total body weight (Fig. 5). The period of greatest increase in height (peak height velocity) coincided with that of the maximum increase in lean body mass and total body weight (Fig. 5). Nevertheless, lean and total body mass increased during the following years relatively more than body height, which was closely related to changes in the proportionality of the organism (characterized by relative values of biacromial and bicristal breadths (PAŘÍZKOVÁ 1968b, 1972) or in the somatotypes (CARTER and PAŘÍZKOVÁ 1974) etc. — Depot fat fluctuated during the whole experimental period, but its greatest increase occurred at the same time as in height, total and lean body weight. However, even at that time the increase was in the mean quite small and insignificant. This was caused by marked inter-individual variability in depot fat development, mostly due to a different energy turnover in individual boys resulting from different physical activity regimes etc. (PAŘÍZKOVÁ 1968, 1973a, b, 1974a, b, 1976, PAŘÍZKOVÁ and POLEDNE 1974, PAŘÍZKOVÁ and REVENDA 1973, PAŘÍZKOVÁ and STANKOVÁ 1964, PAŘÍZKOVÁ et al. 1971).

A similarly close relationship existed between the absolute values of heart volume and lean body mass, weight, arm and thigh circumferences, as well as relative heart volume/kg weight and lean body mass ratio (Tab. 2) in the individual years of the longitudinal study with boys (ČERMÁK and PAŘÍZKOVÁ 1974). Heart volume is, therefore, also closely related to body composition. As in previous parameters, all relationships mentioned were closest at the age of 14—15 years. The same applies to a previous analysis of the relationship of somatic parameters and lean body mass to aerobic capacity (maximum oxygen uptake) during five years in 96 boys (PAŘÍZKOVÁ and ŠPRYNAROVÁ 1968, 1970, ŠPRYNAROVÁ 1974). It seems, therefore, that at the end of puberty

Table 2

Correlation coefficients of the relationship between the heart volume and different morphological parameters of boys in individual years (10.7—17.7 years of age, 1961—68; n = 39; ČERMÁK and PAŘÍZKOVA 1974)

2. táblázat. A szívtérfogat és különböző morfológiai paraméterek közötti viszony korrelációs koefficiensei fiúknál az egyes években (10,7—17,7 éves korban, 1961—68; *n* = 39; ČERMÁK és PAŘÍZKOVA 1974)

Years of measurement *A vizsgálat éve*	Age *Életkor*	Heart volume — *Szívtérfogat* (ml)					r^*
		Height *Testmagasság* (cm)	Weight *Testsúly* (kg)	Lean body mass *Sovány testtömeg* (kg)	Arm circumference *Felkarkerület* (cm)	Thigh circumference *Combkerület* (cm)	
1961	10—11	—	—	0.69	0.28	0.28	0.46
1962	11—12	0.54	0.48	0.59	0.27	0.32	0.39
1963	12—13	0.67	0.77	0.83	0.25	0.38	0.59
1964	13—14	0.76	0.81	0.87	0.48	0.47	0.53
1965	14—15	0.74	0.74	0.84	0.60	0.59	0.47
1966	15—16	0.51	0.49	0.76	0.43	0.44	0.51
1967	16—17	0.38	0.55	0.74	0.27	0.43	0.43
1968	17—18	0.37	0.57	0.72	0.05	0.34	0.38

$^*r$ = Correlation coefficients of the relationships between relative heart volume (i.e. heart volume in ml per body weight n kg) and percent of lean body mass (% LBM in the body).
r = *A relatív szívtérfogat (szívtérfogat ml-ekben/testsúly kg-okban) és a százalékban kifejezett sovány testtömeg kapcsolatának korrelációs koefficiensei.*

maturation processes as well as somatic and functional development are in very good harmony, which affords a basis for high-level physical performance capacity and interest in exercise. This conclusion also agrees with the findings about the natural peaks in various indicators mentioned above e. g. aerobic capacity or heart volume as related to total and lean body mass. These also occur at the age of 14—15 years, when the tendency for motor activity spontaneously attains very high level. Various further measurements have shown that the capacity for work in the adolescent organism is higher than has been usually supposed (this is occasionally showed in the extreme cases of Olympic winners in selected sports). But later on, this capacity decreases in untrained subjects what could be prevented by systematic training (ŠPRYNAROVÁ 1974). Generally, motor stimulation and work-load in youth are on a very low level in the conditions of life in the industrially developed countries, the functional potentionalities of the organism obviously do not fully develop, and the resulting fitness and performance capacity remain fairly low in a relatively great proportion of the adolescents (especially when the acceleration of morphological growth is taken into consideration). This is clearly apparent later on e. g. in university students, in whom the level of physical performance in the mean is rather low; a considerable proportion of students is unable to achieve minimum limits of fitness tests even in the first year of studies, which is markedly worsened during the following 2—4 years of studies (FUČIK 1975). A great number of students also has to attend special physical education classes or has to be completely exempted from such.

Selected data seem to indicate that morphological acceleration is not always paralleled by a correspondingly accelerated functional development in normal untrained population during puberty. This refers mostly to the industrially developed countries, where these surveys were taken. (Of course, this does not apply to small selected groups of highly disposed and trained top athletes.) Lack of proper motor stimulation during the whole growth period could be the reason of this disproportion also resulting in a relatively poorer development of the heart muscle and overall functional capacity KALUZHNAYA 1974, PAŘÍZKOVÁ and ŠPRYNAROVA 1970). The example of boys and girls systematically pursuing physical exercise shows, that the morphological and functional as well as motor development can be in optimum harmony (JUŘINOVÁ et al. 1974, MERHAUTOVÁ and PAŘÍZKOVÁ 1973, PAŘÍZKOVÁ 1974a, PAŘÍZKOVÁ and ŠPRYNAROVÁ 1970, PAŘÍZKOVÁ et al. 1971, ŠPRYNAROVÁ 1974) which affords a sound basis of an advantageous functional development and optimal health prognosis for following periods of life.

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SERDÜLŐKORI VÁLTOZÁSOK A TESTÖSSZETÉTELBEN ÉS A FUNKCIONÁLIS FEJLŐDÉSBEN

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(Összefoglalás)

A serdülőkori növekedés meggyorsulása során a sovány testtömeg, összehasonlítva más morfológiai jellegekkel, relative a legtöbbet növekszik. A sovány testtömeg legnagyobb növekedése a serdülőkori növekedési lökés periódusában jelentkezik. A sovány testtömeg növekedésének trendje a pubertás során jellemző egyedi stabilitást mutat, hasonlóan a testmagassághoz. Az aerob kapacitás, a szívtérfogat, az izomerő stb. növekedése párhuzamosan halad a sovány testtömeg növekedésével. Az aerob kapacitás és a szívtérfogat csúcsértékei, a teljes és a sovány testtömeghez viszonyítva, a 14—15 éves korban jelennek meg, kimutatva azok optimális fogékonyságát a fizikai teljesítményre a fejlődésnek ebben a szakaszában.

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