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Cardiopulmonary Adjustment and Metabolic Response to Maximal and Submaximal Physical Exercise of Boys and Girls at Different Stages of Maturity

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Summary. Cardiopulmonary and metabolic variables were investigated at maximal and submaximal bicycle ergometer exercises in 41 swimmers of both sexes, 8–18 years old. $\dot{V}O_2$ max and $\dot{V}O_2$ max · HR^{-1} were higher in boys than in girls and increased with maturity, while $\dot{V}O_2$ max · kg^{-1} and HVE were not influenced by this. The HV increased clearly during this growth period, the pubertal and postpubertal subjects showing 16 and 17% higher values for HV and HV · kg^{-1} than those reported in normal schoolchildren populations. During the submaximal exercise at 70% $\dot{V}O_2$ max the highest HR values were found in the prepubertal group, whilst the lowest were observed in the postpubertal subjects. These findings suggest that a given percentage of $\dot{V}O_2$ max as a reference unit, is more reliable than a certain HR to obtain comparable results in subjects with different ages.

Blood samples were collected before, during, and after the submaximal exercise. Blood glucose and FFA did not differ in relation to the stages of maturity. During exercise, insulin decreased in prepubertal children, did not alter in pubertal adolescents, and increased in postpubertal subjects. The lactate concentration, during exercise, increased in relation to maturity. The same results were found for HGH, but no differences were found with regard to sex. Since the pattern of HGH secretion during exercise is similar to that found after arginine and insulin administration it is assumed that the same mechanism (i.e., sex hormones) triggers the HGH release.

Key words: Exercise – Puberty – Lactate – Human growth hormone – Heart volume.

Abbreviations: HV = heart volume; HV · kg^{-1} = heart volume per kg body weight; HR = heart rate; $\overline{HR}$ = average heart rate during the submaximal exercise; WL = work load; W · kg^{-1} = watts per kg body weight; $\dot{V}O_2$ max = maximal oxygen consumption; 70% $\dot{V}O_2$ max = 70% of maximal oxygen consumption; $\dot{V}O_2$ max · HR^{-1} = oxygen pulse; HVE = heart volume equivalent (HV/$\dot{V}O_2$ max · HR^{-1}); FFA = free fatty acids; HGH = human growth hormone.

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Short and submaximal physical exercise is a typical and spontaneous activity in childhood and adolescence and is often used in training programs. Since many changes occur in the hormonal, metabolic, cardiovascular, and pulmonary system during the pubertal growth period, different adaptations to physical exercise could be expected during this age. In order to evaluate some hormonal, metabolic, and body changes in this growth period the subjects were divided into different stages of maturity and not into age or weight groups. It was considered that the classification into maturity groups enables a more distinct division than that into age groups because of different hormonal status in subjects with the same age; this may be of importance not only for studying hormones. Boys and girls, with predominantly the same type of physical activity (swimming), with similar intensity (moderate) and frequency (regular), were chosen for our investigation.

Methods

Subjects. 51 pupils (25 boys and 26 girls, aged 8–18) were examined by bicycle ergometer tests. 10 subjects were eliminated because of deviation from the postulated 70 ± 8% $\dot{V}O_2$ max, failure of blood sampling or difficulties in classification into the three stages of maturity. All subjects had taken part in the regular training programs for swimmers at the Bundesleistungszentrum in Heidelberg for at least 2 years.

The subjects were divided into the prepubertal, pubertal, and postpubertal stage according to the classification of Tanner (1969). Criteria for the classification were, for the boys, the penis size, the volume of testes (measured with Prader's orchidometer), pubic hair and, for the girls, breast development, pubic hair, and menarche.

Heart Volume. The HV was determined according to Musshoff et al. (1956) using posterioanterior and lateral x-rays with the subjects standing and in inspiration. The x-ray apparatus was driven by ECG to obtain pictures in the diastole.

Maximal Exercise. The spiroergometer test was performed on a Siemens Elema bicycle ergometer in combination with the Sirognost Siemens equipment. The following values were continously registered: $\dot{V}O_2$, $\dot{V}O_2 \cdot HR^{-1}$, $\dot{V}O_2 \cdot kg^{-1}$, W, and HR. The test was performed in the sitting position according to the general directions of the Deutscher Sportbund: the initial WL was chosen according to the body weight. The WL was increased by the amount of the initial WL every 2 min until exhaustion. The $\dot{V}O_2$ during the last minute of the highest WL was considered the $\dot{V}O_2$ max.

Submaximal Exercise. All subjects attended the laboratory in the morning, after an overnight fast from 21.00 h the previous evening. They were instructed to avoid physical activity in the morning before the ergometer test. A short catheter (Longdwel Catheter-Needle) was inserted into the antecubital vein after which the subjects rested, lying for 40 min; at the end of the rest period the first blood sample was taken (t_1). After this, they mounted the ergometer and cycled with zero WL for 3 min. The WL was subsequently increased during the first 3–5 min up to 70% $\dot{V}O_2$ max, then the WL was varied to maintain a constant $\dot{V}O_2$. In the last minute of the test (15th min) the second blood sample (t_2) was taken. After the test the subjects rested, lying for 10 min and the third blood sample was taken at the last minute rest (t_3).

Blood Determinations. Blood glucose was determined enzymatically (oxidase-peroxidase-method) with a Beckman glucose analyzer and lactate with Boehringer-Biochemica-test-combination according to Hohorst 1970. The remaining blood was centrifuged and aliquots stored at −20° C for further usage. HGH was determined by RIA according to Schalch and Parker (1964) using material provided by Sorin, Saluggia (Italy) and insulin by RIA according to Herbert et al. (1965) with material provided by

Schwarz/Man, New York. The determination of FFA was performed by potentiometric end-point titration (Wirth et al., 1976).

Statistical Methods. For paired data the Wilcoxon rank test was applied. Differences among the three stages of maturity were tested by the analysis of variance using the original values if the distribution was normal. Logarithms were used for the analysis of variance in those cases where the distributions were not normal.

Results

The HV increased during maturity, but the HV · kg^{-1} remained constant among the different growth groups (Table 1). Boys had a larger HV and the HV · kg^{-1} seemed to be larger, too, but the latter difference was not statistically significant.

The $\dot{V}O_2$ max and the $\dot{V}O_2$ max · HR^{-1} increased clearly with maturity, the boys showing higher values than the girls (Table 2). The same sexual difference could be noticed in $\dot{V}O_2$ max · kg^{-1} without any difference concerning the growth periods. No difference neither due to maturity nor to sexes could be detected for the HVE. The performed W · kg^{-1} increased slightly with maturity and differences between boys and girls were not significant.

Table 1. Age, body height, body weight, and heart volume of boys and girls at different stages of maturity

Stage of Maturity		n	Age (years)	Body height (cm)	Body weight (kg)	Heart volume (ml)	Heart volume (ml · kg^{-1})
Prepubertal ①							
Boys	$\bar{x}$	7	10.8	150	37.8	403	10.8
Girls	$\bar{x}$	7	10.4	144	34.3	342	10.0
Boys and girls	$\bar{x}$	14	10.6	147	36.0	375	10.4
	$s_{\bar{x}}$		0.4	2	1.3	10	0.4
Pubertal ②							
Boys	$\bar{x}$	7	12.7	160	46.5	561	11.9
Girls	$\bar{x}$	8	12.4	155	44.8	446	9.7
Boys and girls	$\bar{x}$	15	12.5	157	45.6	503	10.8
	$s_{\bar{x}}$		0.3	2	1.6	34	0.6
Postpubertal ③							
Boys	$\bar{x}$	6	16.9	180	69.8	857	12.3
Girls	$\bar{x}$	6	15.9	166	53.8	552	10.4
Boys and girls	$\bar{x}$	12	16.4	173	61.8	755	11.7
	$s_{\bar{x}}$		0.7	3	2.7	64	0.9
Analysis of variance							
① – ②	p		< 0.01	< 0.01	< 0.01	< 0.01	n.s.
① – ③	p		< 0.01	< 0.01	< 0.01	< 0.01	0.05
② – ③	p		< 0.01	< 0.01	< 0.01	< 0.01	n.s.
① – ② – ③	p		< 0.01	< 0.01	< 0.01	< 0.01	n.s.

Table 2. Oxygen consumption, physical working capacity, and pulse rate during maximal and submaximal working performance of boys and girls at different stages of maturity

Stage of maturity		n	Maximal performance			
			$\dot{V}O_2$ (ml · min^{-1})	$\dot{V}O_2 \cdot kg^{-1}$ (ml · min^{-1} · kg^{-1})	$\dot{V}O_2 \cdot HR^{-1}$ (ml)	HR (min^{-1})
Prepubertal ①						
Boys	$\bar{x}$	7	1931	50.6	10.2	180
Girls	$\bar{x}$	7	1514	44.2	7.6	192
Boys and girls	$\bar{x}$	14	1723	47.2	8.9	186
	$s_{\bar{x}}$		97.8	1.73	0.58	5.0
Pubertal ②						
Boys	$\bar{x}$	7	2244	48.3	12.0	183
Girls	$\bar{x}$	8	1937	40.3	10.3	186
Boys and girls	$\bar{x}$	15	2080	44.0	11.1	185
	$s_{\bar{x}}$		144.0	3.01	0.62	3.2
Postpubertal ③						
Boys	$\bar{x}$	6	3410	48.7	19.9	176
Girls	$\bar{x}$	6	2398	44.4	14.0	178
Boys and girls	$\bar{x}$	12	2895	46.5	17.0	177
	$s_{\bar{x}}$		197.0	1.77	1.12	3.1
Analysis of variance						
① – ②	p		< 0.05	n.s.	< 0.05	n.s.
① – ③	p		< 0.01	n.s.	< 0.01	n.s.
② – ③	p		< 0.01	n.s.	< 0.01	< 0.05
① – ② – ③	p		< 0.01	n.s.	< 0.01	n.s.

Stage of maturity		n	Maximal performance		Submaximal performance		
			HVE	WL (watts · kg^{-1})	% $\dot{V}O_2$ max (ml · min^{-1})	$\dot{V}O_2 \cdot kg^{-1}$ (ml · min^{-1} · kg^{-1})	$\overline{HR}$ (min^{-1})
Prepubertal ①							
Boys	$\bar{x}$	7	40.4	3.0	69.3	40.2	168
Girls	$\bar{x}$	7	47.1	3.6	68.8	33.1	168
Boys and girls	$\bar{x}$	14	43.5	3.4	69.1	35.3	168
	$s_{\bar{x}}$		1.98	0.17	0.97	1.30	3.2
Pubertal ②							
Boys	$\bar{x}$	7	46.1	4.2	69.6	35.4	141
Girls	$\bar{x}$	8	43.0	3.6	69.5	29.3	160
Boys and girls	$\bar{x}$	15	44.6	3.9	69.5	32.7	151
	$s_{\bar{x}}$		1.82	0.14	1.41	1.72	4.2
Postpubertal ③							
Boys	$\bar{x}$	6	43.1	3.9	69.8	37.7	138
Girls	$\bar{x}$	6	38.0	4.0	68.5	34.7	145
Boys and girls	$\bar{x}$	12	41.4	4.0	69.2	36.2	142
	$s_{\bar{x}}$		1.78	0.13	1.21	1.55	4.9
Analysis of variance							
① – ②	p		n.s.	< 0.05	n.s.	n.s.	< 0.01
① – ③	p		n.s.	< 0.05	n.s.	n.s.	< 0.01
② – ③	p		n.s.	n.s.	n.s.	n.s.	n.s.
① – ② – ③	p		n.s.	< 0.05	n.s.	n.s.	< 0.01

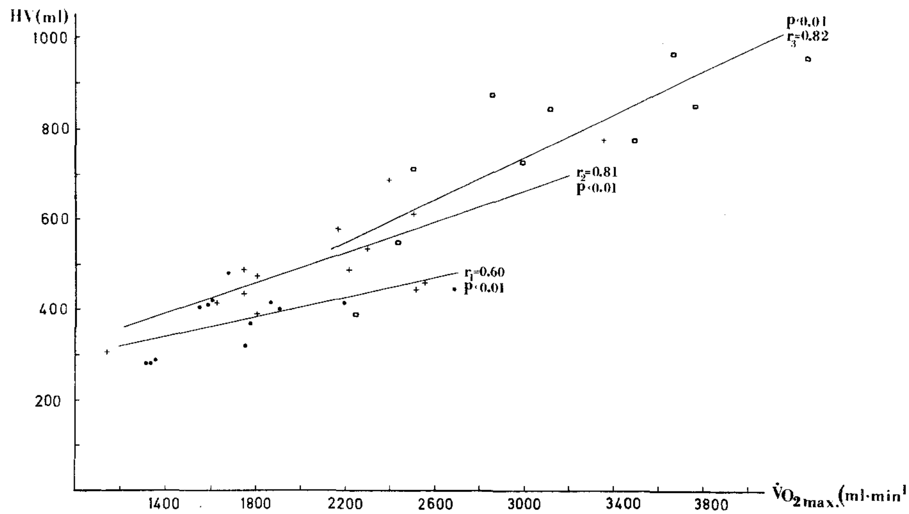

Fig. 1. Correlation between heart volume and maximal oxygen consumption of boys and girls at different stages of maturity. r_1 = correlation coefficient for prepubertal subjects (······), r_2 = for pubertal subjects (+ + + +), and r_3 = for postpubertal subjects (□□□□)

Although the percentage of the $\dot{V}O_2$ max was the same in all groups, the $\overline{HR}$ was high in the prepubertal group, significantly lower in the pubertal subjects, and still lower in the postpubertal group.

Figure 1 shows that the well known relationship between HV and $\dot{V}O_2$ max changes with maturity; on average with increasing maturity, higher HV values were found at the same $\dot{V}O_2$ max.

Table 3 shows the metabolic variables with regard to sex and stages of maturity during rest (t_1), at the end of the submaximal exercise (t_2), and 10 min after the test (t_3). Blood glucose changed little during the test, without any differences among groups and sexes. Lactate increased as a result of physical exercise in all the three groups and 10 min after cessation of work the values were still higher than during the rest. The lactate increase at t_2 and t_3 was related to the stages of maturity: the higher the maturity stage, the higher the increments in lactate. The concentration of FFA did not change during exercise. In the recovery period an increase could be noticed in all the groups. Differences between sexes or stages of maturity were not found.

The hormonal changes are shown in Table 4. Insulin decreased during exercise in prepubertal children, showed no changes in pubertal adolescents, and increased in postpubertal subjects. In the recovery period there was a tendency toward higher concentrations compared to the resting values (with exception of Group 1). The insulin levels did not differ in the two sexes or any of the groups at the various times. HGH increased during exercise in all groups, postpubertal subjects showing the highest concentrations and prepubertal children the lowest ones. This difference still existed during the recovery period, but no differences were found with regard to sex. No correlation could be detected between HGH increments and changes in lactate, FFA, or insulin.

Table 3. Blood glucose (mg/100 ml), blood lactate (mMol/l), and FFA (μMol/l) before (t_1), at the end the submaximal exercise (t_2), and 10 min after the test (t_3)

		n	t_1		t_2		t_3
Blood glucose							
Prepubertal ①							
Boys	$\bar{x}$	7	85.1		92.7		90.7
Girls	$\bar{x}$	7	88.0		95.7		91.7
Boys and girls	$\bar{x}$	14	86.6		94.2		91.2
	$s_{\bar{x}}$		1.8		2.9		2.6
	p			< 0.05		n.s.	
Pubertal ②							
Boys	$\bar{x}$	7	82.4		86.1		87.4
Girls	$\bar{x}$	8	82.1		88.1		90.6
Boys and girls	$\bar{x}$	15	82.3		87.2		89.1
	$s_{\bar{x}}$		2.1		2.3		2.6
	p			n.s.		< 0.05	
Postpubertal ③							
Boys	$\bar{x}$	6	82.7		85.0		90.2
Girls	$\bar{x}$	6	82.5		85.3		83.3
Boys and girls	$\bar{x}$	12	83.1		85.2		86.7
	$s_{\bar{x}}$		3.1		4.6		3.8
	p			n.s.		n.s.	
Lactate							
Prepubertal ①							
Boys	$\bar{x}$	7	0.82		2.03		1.46
Girls	$\bar{x}$	7	0.93		2.41		1.62
Boys and girls	$\bar{x}$	14	0.87		2.22[b]		1.54[b,c]
	$s_{\bar{x}}$		0.08		0.21		0.17
	p			< 0.01		< 0.01	
Pubertal ②							
Boys	$\bar{x}$	7	1.03		2.45		1.61
Girls	$\bar{x}$	8	0.89		2.72		1.89
Boys and girls	$\bar{x}$	15	0.96		2.59[c]		1.76[c]
	$s_{\bar{x}}$		0.09		0.17		0.10
	p			< 0.01		< 0.01	
Postpubertal ③							
Boys	$\bar{x}$	6	0.92		3.40		2.70
Girls	$\bar{x}$	6	1.20		3.33		2.11
Boys and girls	$\bar{x}$	12	1.06		3.36[b,c]		2.41[b,c]
	$s_{\bar{x}}$		0.08		0.39		0.38
	p			< 0.01		< 0.01	
Free fatty acids							
Prepubertal ①							
Boys	$\bar{x}$	7	548		478		639
Girls	$\bar{x}$	7	458		426		674
Boys and girls	$\bar{x}$	14	503		452		656
	$s_{\bar{x}}$		46		38		77
	p			n.s.		< 0.05	

[a] significant difference ($p < 0.05$) between group ① – ②
[b] significant difference ($p < 0.05$) between group ① – ③
[c] significant difference ($p < 0.05$) between group ② – ③

Table 3 (continued)

		n	t_1		t_2		t_3
Pubertal ②							
Boys	$\bar{x}$	7	461		554		701
Girls	$\bar{x}$	8	611		590		649
Boys and girls	$\bar{x}$	15	554		573		673
	$s_{\bar{x}}$		51		66		76
	p			n.s.		< 0.01	
Postpubertal ③							
Boys	$\bar{x}$	6	466		371		609
Girls	$\bar{x}$	6	608		684		880
Boys and girls	$\bar{x}$	12	537		528		745
	$s_{\bar{x}}$		65		78		94
	p			n.s.		< 0.05	

Discussion

Cardiopulmonary Adjustment

The HV values found in our prepubertal swimmers, are in close agreement with those reported by Musshoff et al. (1961), Shephard et al. (1969), Hollmann and Bouchard (1970), and Bouchard et al. (1977) in normal populations of schoolchildren and slightly lower than those by Čermák (1968) (Table 5). If the HV and HV $\cdot$ kg^{-1} of our pubertal and postpubertal group are compared to those reported in adolescents without any regular physical training 3–30% (average 16%) and 8–22% (average 17%) higher values can be found, respectively. The more pronounced increase in HV and the rise in HV $\cdot$ kg^{-1} by about 17% (compared to normal pupil populations) during the pubertal growth spurt indicates a marked sensitivity of the heart growth to repeated physical efforts. The clinical significance of these observations remains to be demonstrated.

As a result of regular swimming the $\dot{V}O_2$ max values were 11% higher than those reported by Musshoff et al. (1961) and Hollmann and Bouchard (1970) (comparing the age groups). The increase of $\dot{V}O_2$ max and $\dot{V}O_2$ max $\cdot$ HR^{-1} with maturity, the boys showing higher values than the girls, are in agreement with investigations of Musshoff et al. (1961). Hollmann et al. (1965), Shephard et al. (1969), and Bouchard et al. (1977). Máček and Vávra (1971) found a diminished $\dot{V}O_2 \cdot$ kg^{-1} with increasing weight in 6–14 years old children of both sexes during submaximal exercise. We did not observe this trend at maximal and submaximal WL's nor did Shephard et al. (1969) and Musshoff et al. (1961). This difference may be explained by the fact that Máček referred the WL to the body weight.

As mentioned above, we have chosen a given $\dot{V}O_2$ of $\dot{V}O_2$ max as a reference unit to obtain comparable physical work loads in all stages of maturity for both sexes. As indicated in Table 2, the $\overline{HR}$ during the submaximal exercise (not the maximal HR) showed a relationship to the growth stage; the higher the stage of maturity, the lower the $\overline{HR}$. Figure 1 shows that the regression line for the three

Table 4. Insulin (μU/ml) and HGH (ng/ml) before (t_1), at the end of the submaximal exercise (t_2), and 10 min after the test (t_3)

		n	t_1		t_2		t_3
Insulin							
Prepubertal ①							
Boys	$\bar{x}$	7	13.0		10.0		11.1
Girls	$\bar{x}$	7	10.6		8.9		12.6
Boys and girls	$\bar{x}$	14	11.7		9.4		11.8
	$s_{\bar{x}}$		1.3		1.0		1.0
	p			< 0.01		n.s.	
Pubertal ②							
Boys	$\bar{x}$	7	12.8		12.3		15.0
Girls	$\bar{x}$	8	12.0		11.1		13.7
Boys and girls	$\bar{x}$	15	12.4		11.6		14.2
	$s_{\bar{x}}$		1.3		1.5		1.9
	p			n.s.		< 0.01	
Postpubertal ③							
Boys	$\bar{x}$	6	9.4		11.9		13.4
Girls	$\bar{x}$	6	9.1		12.7		10.4
Boys and girls	$\bar{x}$	12	9.3		12.3		12.2
	$s_{\bar{x}}$		0.7		1.7		1.3
	p			< 0.05		< 0.05	
HGH							
Prepubertal ①							
Boys	$\bar{x}$	7	1.61		7.62		8.23
Girls	$\bar{x}$	7	1.76		7.06		6.49
Boys and girls	$\bar{x}$	14	1.68[b]		7.34[a,b]		7.36[b]
	$s_{\bar{x}}$		0.59		1.24		1.36
	p			0.01		0.01	
Pubertal ②							
Boys	$\bar{x}$	7	3.22		14.98		9.67
Girls	$\bar{x}$	8	2.97		13.28		8.49
Boys and girls	$\bar{x}$	15	3.08[b,c]		14.07[b,c]		9.04[b,c]
	$s_{\bar{x}}$		1.09		2.56		1.32
	p			0.01		0.01	
Postpubertal ③							
Boys	$\bar{x}$	6	10.09		20.32		17.27
Girls	$\bar{x}$	6	6.33		19.43		12.93
Boys and girls	$\bar{x}$	12	8.21[b,c]		19.87[b,c]		15.13[b,c]
	$s_{\bar{x}}$		2.09		3.25		2.17
	p			< 0.01		< 0.01	

[a] significant difference ($p < 0.05$) between group ① – ②
[b] significant difference ($p < 0.05$) between group ① – ③
[c] significant difference ($p < 0.05$) between group ② – ③

Table 5. Heart volume and heart volume per kg body weight in different studies

	Sex	Age (years)	Weight (kg)	Height (cm)	HV (ml)	HV · kg^{-1} (ml · kg^{-1})
Boys and girls						
Current study (Group 1)	M + F	10.6	36.0	147	379	10.4
Shephard et al., 1969	M + F	9 + 10 + 11	36.1	–	376	10.4
Bouchard et al., 1977	M + F	10 + 11	34.6	147	345	10.2
Current study (Group 2)	M + F	12.5	45.6	157	503	10.8
Čermák et al., 1968	M + F	12 + 13	42.7	153	488	11.4
Shephard et al., 1969	M + F	12 + 13	41.4	–	376	9.7
Bouchard et al., 1977	M + F	12 + 13	41.7	157	419	10.2
Current study (Group 3)	M + F	16.4	61.8	173	755	11.7
Bouchard et al., 1977	M + F	16 + 17	64.8	175	625	10.2
Boys						
Current study (Group 1)	M	10.8	37.8	150	403	10.8
Hollmann et al., 1965	M	10.8	–	–	~ 365	–
Musshoff et al., 1961	M	10 + 11	35.2	145	411	11.7
Hollmann et al., 1970	M	10.8	–	–	~ 395	–
Current study (Group 2)	M	12.7	46.5	160	561	11.9
Musshoff et al., 1961	M	12 + 13	45.0	156	509	11.3
Hollmann et al., 1965	M	12.7	–	–	~ 430	–
Hollmann et al., 1970	M	12.7	–	–	~ 460	–
Current study (Group 3)	M	16.9	69.8	180	857	12.3
Musshoff et al., 1961	M	17.5	65.0	176	743	11.4
Hollmann et al., 1965	M	16.9	–	–	~ 690	–
Hollmann et al., 1970	M	16.9	–	–	~ 720	–

different groups rises with the stage of maturity. This means that especially in prepubertal children, a higher $\dot{V}O_2$ may be reached by increasing the HR rather than the heart stroke volume. On the other hand the dependence of the HR on the stage of maturity or age at a certain percentage of $\dot{V}O_2$ max demonstrates that experiments with a given submaximal HR in subjects with varying ages is problematic. In some investigations cardiopulmonary variables have been measured in different age groups at a certain submaximal HR (Mocellin et al., 1971; Bouchard et al., 1977). Our results indicate that the applied relative WL in those studies was lower in younger subjects and higher in older ones.

Metabolic and Endocrine Responses

Eriksson (1971) measured lower lactate concentrations in 11–13 year-old boys than in adults during exercise. Máček et al. (1976) mentioned the same distinction comparing his results in prepubertal boys with those Ekblom et al. (1968) obtained in adults at approximately the same percentage of $\dot{V}O_2$ max. Our results confirm that exercise-induced increments in lactate are dependent on maturity. The failure to achieve a true maximum $\dot{V}O_2$ especially in some prepubertal and pubertal children may have contributed to the lower lactate levels in these groups. But we assume that this fact can only in part explain the differences in lactate concentrations among the three maturity groups. From a theoretical point of view, changes in insulin concentrations might have influenced lactate levels. As shown in Table 4, insulin decreased in prepubertal subjects and increased in postpubertal ones. This means that increasing insulin levels go along with increasing lactate concentrations. In this context it is interesting to notice that insulin deficient diabetics show lower lactate levels (Nordlander et al., 1973; Weicker et al., 1976) and a higher removal of lactate by the splanchnic tissue (Wahren et al., 1972) than healthy controls during exercise. The reason for the lower lactate concentrations in children during exercise may be due to a reduced ability to form lactate, a greater extent of dilution because of a relatively higher total water content, or to an enhanced metabolism. If the first assumption is true, the lower insulin levels during exercise may reduce the glucose oxidation via the glucolytic pathway. This presumption is supported by the fact that the phosphofructokinase activity is lower in children than in adults (Eriksson, 1972) and phosphofructokinase has been considered to be the rate limiting enzyme for the glycolysis (Danforth and Lyon, 1964). For practical purpose the reduced lactacid anaerobic capacity in children indicates that alactacid aerobic exercise should have preference. As for sex differences in lactate increments during exercise, Máček and Vávra (1971) found higher levels in girls than in boys. This difference was neither observed in the current study nor by Shephard et al. (1969) during maximal and submaximal efforts. Máček and Vávra (1971) applied various WL referred to the body weight. Since he found higher $\dot{V}O_2$ values in boys than in girls at maximal WL's but not at the same WL per kg body weight, it can be assumed that during the latter type of exercise the girls were exposed to relative higher $\dot{V}O_2$ values; this may explain their higher concentrations in girls.

A decrease in insulin concentration during prolonged (Pruett, 1970) or heavy exercise (Weicker et al., 1976) in adults have been reported. In this study, applying a moderate and short exercise, we found different changes with regard to the three defined stages of maturity. If the alterations in the insulin concentration during exercise are due to changes in insulin secretion influenced by catecholamines, higher catecholamine concentrations or a higher sensitivity to catecholamines could be assumed. Conversely the well known insulin "rebound" after physical exercise may be explained by decreasing catecholamine concentrations.

Plasma HGH concentrations and stimulation of HGH secretion are age-dependent. If HGH secretion is stimulated by insulin-induced hypoglycemia the peak value in children is much lower than in adults (Root et al., 1969). Frantz and Rabkin (1965) and Merimee et al. (1966) found sex differences in adults after arginine infusion with a lower peak response in males whereas this sex difference could not be noticed in prepubertal children (Youlton et al., 1969). Moreover, the HGH response to arginine is increased in males after stilboestrol administration (Merimee et al., 1966). The observed age and sex differences may be explained by androgens and estrogens since their production rates increase rapidly with the onset of puberty and estrogens stimulate the HGH release to a greater extent than testosterone (Zachmann and Prader, 1972). Thus, the HGH secretion, we found less pronounced in prepubertal children than in postpubertal adolescents, during exercise, can be explained by differences in sex hormone concentrations. Since androgen and estrogen concentrations are increased during exercise, they may play an important role in releasing HGH (Kuoppasalmi et al., 1976).

The same sex and age difference in HGH after arginine infusion, insulin injection, or during exercise leads to the assumption that the same mechanism triggers the HGH secretion. Since children and adolescents of both sexes have an increasing but still lower secretion of sex hormones than adults (Knorr, 1970), the reason for the blunted HGH response to exercise seems to be due to lower concentrations of androgens and estrogens.

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