METABOLIC EFFECTS OF HEAVY PHYSICAL TRAINING ON FEMALE 'AGE-GROUP' SWIMMERS

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ABSTRACT

Twelve female age-group swimmers and twelve female controls, aged ten to sixteen, performed a pre-training discontinuous maximal cycle ergometer test to determine the capacities of their anaerobic (alactacid and lactacid) and aerobic energy systems. Heart rate and oxygen uptake were determined during rest, exercise, and recovery. Blood samples were collected before and after exercise for determination of blood lactic acid concentrations. Tests were readministered to both groups immediately following the swimmers' competitive season. It was concluded that female swimmers possess significantly superior oxygen transport systems as compared to the untrained controls and that this high level of aerobic fitness is maintained throughout their training programme.

INTRODUCTION

Currently in the United States there are 1½ to 2 million swimmers in some phase of active training for competitive swimming. This large number, which has increased greatly over the last 20 years, has been due to growth of the 'age-group' (17 years of age and younger) swimming programme.

Much of the progress in swimming records has been attributed to the greatly increased difficulty of the training programmes undertaken by competitive swimmers. Some of the recent changes which have developed to prepare swimmers for competition are: (1) the use of interval training, (2) a large increase in the total training distance per average training day, and (3) an increase in the average number of workouts per week during a training year. Because of the success of some outstanding swimmers engaged in such programmes, it has been assumed that such heavy work is always beneficial. The lack of information regarding the physical effects of strenuous training on children indicates considerable need for further studies in this area.

The purpose of this study was to determine the effects of long-term heavy physical training upon selected physiological variables in girls 10 to 16 years of age.

METHODS AND PROCEDURES

The 12 experimental subjects were 10-16 year old girls involved in the successful 'age-group' swimming programme of Upper Arlington, Ohio. Twelve other girls (10-16 years of age) from the local schools in the same

geographical area constituted the control group. The experimental and the control subjects were matched according to chronological age, ponderal index, and body surface area. Physiological age was determined by hand-wrist X-rays. Maturational age was determined by the method of Tanner (1955). These data are summarised in Table I.

A health appraisal, which consisted of examination of the cardiovascular, pulmonary, and musculoskeletal systems, was administered to determine if the subjects were physically able to participate in a strenuous testing programme. After acceptance by the monitoring paediatrician of the study, the subjects were made familiar with the cycle ergometer and the respiratory apparatus, and the testing procedures were explained. A sub-maximal ergometer ride was performed by each subject. An extrapolated minute heart rate was used as an evaluative criterion to determine the initial work load which would be performed at the onset of the maximal ergometer test.

During the pre-training testing session, the subjects performed a maximal ergometer test to determine the capacities of their anaerobic (alactacid and lactacid) and aerobic energy systems. This test utilized a discontinuous loading method and was performed on a Jacquet Universal ergometer at a constant pedalling rate of 60 rpm. The work load was adjusted for each subject so that she would reach exhaustion after approximately

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3 successive rides of 4 minutes each. The rides were separated by a 10 minute rest period.

The open circuit method was used to determine oxygen consumption.

The subject breathed through a scuba mouthpiece. Air was directed from the inlet side of the mouthpiece to the outlet port by means of two one-way valves. Two Parkinson-Cowen CD-4 Gas meters were arranged on the inlet side of the mouthpiece. The volume of the inspired air was determined minute by minute by alternating air intake from one meter to the other. The expired air passed from the outlet of the mouthpiece to a mixing chamber. The gas entering the mixing chamber was dis-

persed by means of a 90 degree angle turn at the inlet to the chamber. Minute determinations of the expired air were drawn from the mixing chamber by means of a Beckman Microcatheter Sample Pump and collected in 3 litre rubber sample bags.

The expired samples were transferred directly into a Beckman LB-1 carbon dioxide analyzer and a Beckman E-2 oxygen analyzer. The oxygen consumption was calculated according to the standard method of Mathews and Fox (1971).

Forearm venous blood samples were taken prior to exercise and 5 minutes following the completion of the maximal test. Blood lactic acid concentrations were

TABLE I
Vital Data

	Subject	Age ^a	Age ^b	Age ^c	Age ^d	Ht ^e	Wt ^f	P.I. ^g	B.S.A. ^h
GROUP I	*C1	10.4	10.0	1.5	0	136.8	33.6	12.8	1.13
8-10 yrs	C2	10.6	11.5	2.0	0	147.1	39.0	13.1	1.27
	C3	10.8	10.8	1.5	0	144.6	38.9	12.9	1.25
GROUP II	C4	11.8	12.0	3.5	0	148.2	39.2	13.2	1.28
11-12 yrs	C5	11.8	11.6		0	148.3	35.0	13.7	1.22
	C6	12.0	12.6	3.5	0	155.9	49.3	12.8	1.46
	C7	12.2	12.4	3.5	0	155.5	38.3	14.0	1.31
GROUP III	C8	14.5	15.0	3.5	12.3	158.8	54.4	12.6	1.55
13-14 yrs	C9	15.0	15.5	4.5	12.8	166.2	60.2	12.8	1.66
GROUP IV	C10	16.1	17.0	5.0	12.0	155.1	51.0	12.7	1.48
15-17 yrs	C11	16.2	15.0*	4.0	14.9	167.3	51.8	13.6	1.57
	C12	16.3	16.0	5.0	11.8	154.1	47.4	12.9	1.43
GROUP I	**E1	10.3	11.5**	1.0	0	150.4	47.3	12.6	1.40
8-10 yrs	E2	10.6	10.0	1.0	0	141.8	30.9	13.7	1.12
GROUP II	E3	11.2	10.0*	1.0	0	147.0	38.2	13.2	1.26
11-12 yrs	E4	11.6	10.5*	2.0	0	147.5	38.2	13.3	1.26
	E5	11.8	11.0	1.5	0	142.5	32.2	13.6	1.15
	E6	12.1	12.5	2.0	0	145.5	38.2	18.1	1.25
GROUP III	E7	13.3	15.0**	4.0	11.9	166.6	62.6	12.7	1.70
13-14 yrs	E8	13.8	15.0**	4.5	12.3	165.6	56.8	13.0	1.63
	E9	14.3	15.0	4.0	13.0	155.0	49.2	12.8	1.46
	E10	14.6	15.0	5.0	11.6	161.1	51.5	13.1	1.53
	E11	14.9	17.0**	5.0	11.6	160.1	51.5	12.6	1.59
GROUP IV	E12	16.2	16.0	3.5	14.9	152.0	49.1	12.6	1.44
15-17 yrs									

* Control

** Experimental

a Chronological age — years

b Physiological age — years

** early maturer

* late maturer

c Maturational age

d Menarcheal age

e Height — centimetres

f Weight — kilograms

g Ponderal Index

h Body surface area (m²)

determined using the colorimetric method of Barker and Summerson (1941). Resting, exercise and recovery heart rates (HR) were recorded using a Hewlett-Packard ECG Model 1500 A.

During the interim between the maximal oxygen uptake tests, the experimental subjects participated in their usual interval training workouts under the direction of their coach. The subjects swam as much as 12,000-14,000 metres per day in as many as 3 workouts, training up to 6 days per week. The control subjects engaged in their regular daily activities, but they were not allowed to train in an organized swimming or track programme.

The post-training maximal ergometer test was administered again to both groups in the spring, immediately following the completion of the swimmers' competitive season. Blood lactic acid concentrations and resting, exercise, and recovery heart rates were also determined.

RESULTS AND DISCUSSION

The cycle ergometer was chosen for the maximal oxygen consumption test because it is a neutral activity requiring a minimum of skill which most children have acquired. The ergometer also meets the standards suggested by Åstrand and Rodahl (1970) for an optimal measurement of exercise fitness.

Investigations of the maximal oxygen uptake during adolescence are relatively few. Allen et al. (1956) studied young girls whose mean max $\dot{V}O_2$ was 38.3 ml/kg-min. Kramer and Lurie (1964) reported a max $\dot{V}O_2$ of 49.5 ml/kg-min. for girl swimmers and 27.5 ml/kg-min. for untrained girls. Cunningham and Eynon (1973) reported mean values of 46.2 ml/kg-min. for girl swimmers 12.2 years old, 43.4 ml/kg-min. for 13.2 year old girl swimmers, and a value of 40.5 ml/kg-min. for girl swimmers 14.9 years of age. Holmer (1972) has reported a mean max. $\dot{V}O_2$ of 58.3 ml/kg-min. for 12 female swimmers, 13 to 18 years of age, when tested by running on a treadmill. His values are above the ones obtained in this study, where the mean max. $\dot{V}O_2$ for the control group for the initial test was 43.8 ml/kg-min. and 43.3 ml/kg-min. for the second test compared to 47.7 ml/kg-min. prior to the competitive season and 48.9 ml/kg-min. at the end of the experimental group's competitive season (Table II). However, the values in this study were obtained by subjects pedalling a cycle ergometer, which may partly explain the reduction. The values of cycling are on an average 5 to 8% lower than those for running (Åstrand, 1971).

The max. $\dot{V}O_2$'s of the experimental subjects in this study were superior to the controls. The swimmers' max. $\dot{V}O_2$ averaged 8.2% higher before training and 11.5% greater after training when compared on the basis of body weight. When expressed in litres/min. the experi-

mental group had a max. $\dot{V}O_2$ which was 10% greater than that of the control group before training and 13.5% higher after the training programme. The difference between the experimental and control groups in terms of their max. $\dot{V}O_2$ was greater in this study than that found between the Swedish champion girl swimmers and ordinary women, where only a 10% difference was displayed (Åstrand et al., 1963).

The maximal $\dot{V}O_2$ of 48.9 ml/kg-min. of the girl swimmers after training in this study is quite similar to the 51.5 ml/kg-min. reported by Åstrand et al. (1963) in their study of girl swimmers. According to the classification in Åstrand's nomogram (1960), the experimental girl swimmers are very close to qualifying for inclusion in the highest category (greater than 49.9 ml/kg-min.). The max. $\dot{V}O_2$ achieved by the swimmers in this study indicates that the functional capacity of the cardio-respiratory system has adapted to the high metabolic demands of the training programme during adolescence. This fact has been demonstrated by the achievement of world records in swimming by girls in their early teens.

Åstrand (1963) states that intensive training during adolescence results in a combination of "normal" body development and the effect of training so that the highest capacity for aerobic processes is reached at an earlier age. According to Åstrand (1952), development during early adolescence in girls normally leads to a great increase in the aerobic capacity from 1.7 l/min. in 10 to 11 year-olds to 2.6 l/min. in 14-15 year-olds. In relation to body weight, the max. $\dot{V}O_2$ decreases by an average of 12% if the older girls are compared with the younger ones. A 12% decrease in max. $\dot{V}O_2$ when expressed in ml/kg-min. was observed between the older and younger swimmers in this study.

Max. $\dot{V}O_2$ is said to be the best single measure of physical fitness (fitness being defined as the ability to do aerobic work). Motivational factors were minimized by requiring that the subject continue until the heart rate approached 200 b/min. or until the subject could no longer continue at 60 rpm. The most accepted criterion that a near maximal level of O_2 uptake has been reached is that the O_2 uptake levels off, failing to increase with an increase in work load. This plateau was noted in three of the control subjects and none of the experimental subjects. The observation was made that the subjects used mostly leg and hip muscles with moderate loads, but at the extreme workloads they strained with their entire bodies by bracing the hands on the handle-bars to get leverage and swinging the body weight from one leg to the other. The level of O_2 uptake with cycle exercise may depend on how willing the subjects are to stress themselves this intensely. For as long as the subject can recruit more muscles to perform the test, the greater should be the diversion of oxygen from the nonworking muscles to the exercising areas. The arteriovenous

TABLE II
Maximal Bicycle Ergometer Test Data

Subject		Max. $\dot{V}O_2$ L./min.	Max. $\dot{V}O_2$ ml./kg-min.	Max. $\dot{V}O_2$ ml./kg. LBW	Max. R.E.R.	Max. $\dot{V}E_{BTPS}$ L./min.	Max. H.R. bpm.	Net L.A. mg. %	Subject		Max. $\dot{V}O_2$ L./min.	Max. $\dot{V}O_2$ ml./kg-min.	Max. $\dot{V}O_2$ ml./kg. LBW	Max. R.E.R.	Max. $\dot{V}E_{BTPS}$ L./min.	Max. H.R. bpm.	Net L.A. mg. %
C1	B	1.38	40.9	54	0.98	41.0	199	52	E1	B	2.22	46.9	66	1.02	81.5	192	21
	A	1.43	40.9	55	1.03	43.8	196	57		A	2.32	49.5	69	1.00	75.7	191	38
C2	B	1.66	42.6	57	0.91	49.2	200	35	E2	B	1.75	56.8	74	0.89	49.6	205	34
	A	1.68	42.1	58	0.97	55.6	200	29		A	1.91	56.5	74	0.96	53.0	202	43
C3	B	1.78	45.9	60	0.85	56.0	206	28	E3	B	1.64	43.0	59	0.90	50.4	206	25
	A	1.89	45.7	62	0.91	62.0	200	24		A	1.79	44.8	59	0.89	50.2	208	38
C4	B	1.98	50.6	65	0.89	51.1	201	21	E4	B	1.88	49.3	64	0.94	58.8	201	39
	A	1.77	43.8	57	1.01	55.0	196	42		A	2.22	52.0	67	0.91	57.7	197	33
C5	B	1.95	55.7	68	1.05	66.7	197	55	E5	B	1.78	55.4	68	0.85	48.9	203	30
	A	1.93	48.8	61	1.03	66.2	184	81		A	1.78	51.7	64	0.92	50.4	206	38
C6	B	2.03	41.1	53	1.19	92.1	191	79	E6	B	1.80	47.0	63	0.88	46.8	201	21
	A	2.37	46.7	60	1.17	100.6	192	79		A	1.91	48.9	65	0.86	49.6	198	33
C7	B	2.00	52.1	65	0.91	67.2	202	70	E7	B	2.91	46.5	62	0.96	82.1	192	48
	A	1.94	47.9	60	1.11	70.5	202	73		A	2.98	48.6	65	0.98	80.5	193	48
C8	B	1.86	34.2	45	0.86	44.1	195	39	E8	B	2.75	48.5	67	0.96	94.2	196	68
	A	1.91	34.2	47	1.07	59.5	191	58		A	2.85	49.5	65	0.98	85.2	192	45
C9	B	2.41	40.1	53	0.92	59.4	190	48	E9	B	2.19	44.5	58	0.96	56.5	203	74
	A	2.59	42.8	57	1.00	71.6	192	54		A	2.48	48.4	63	0.95	58.7	205	
C10	B	2.24	43.9	57	0.98	77.9	192	81	E10	B	2.46	47.9	64	0.95	77.8	201	37
	A	2.50	48.8	66	1.00	88.8	193	88		A	2.32	46.2	61	0.91	62.9	202	30
C11	B	2.00	38.6	50	1.05	80.3	183		E11	B	2.12	37.1	51	0.88	47.9	193	15
	A	1.82	35.4	46	1.10	67.8	182			A	2.58	44.1	58	0.94	59.2	200	39
C12	B	1.88	39.8	53	1.00	79.6	188	118	E12	B	2.42	49.4	67	0.99	84.7	190	62
	A	2.02	42.0	59	1.16	82.1	186	98		A	2.46	46.6	64	0.87	81.8	195	65
MEAN	B	1.93	43.8	57	0.97	63.7	195	57	MEAN	B	2.16	47.7	64	0.93	64.9	199	40
S.D.		± 0.26	± 6.2	± 7	± 0.10	± 16.2	± 7	± 28	S.D.		± 0.41	± 5.2	± 6	± 0.05	± 17.6	± 6	± 20
MEAN	A	1.99	43.3	57	1.05	68.6	193	62	MEAN	A	2.30	48.9	65	0.93	63.7	199	41
S.D.		± 0.34	± 4.8	± 6	± 0.08	± 15.7	± 6	± 24	S.D.		± 0.40	± 3.4	± 4	± 0.04	± 13.4	± 6	± 10

B = Before (Pre) Season A = After (Post) Season

oxygen difference will increase and so should the O_2 uptake.

Pulmonary ventilation in relation to oxygen consumption appeared to be similar in the experimental and control groups up to a level of 70 to 80% of the max. $\dot{V}O_2$. At this level the hyperventilation characteristic of heavy work began, and was more pronounced in the control group than in the experimental subjects. The noted difference in the pulmonary ventilation was significant between the experimental and control groups at maximal levels.

The maximal respiratory exchange ratio (max. R.E.R.) was statistically higher in the control group as compared to the experimental group. Most of the R.E.R.'s of the control group were above unity and, therefore, indicated that lactic acid was being thrown into the blood during the work period. Lactic acid is produced by the muscles when the work is heavy enough to require a greater anaerobic liberation of energy than the alactacid process can furnish (Newman et al., 1937).

Of interest is the fact that the R.E.R.'s were lower in the experimental group, probably due to the long term training programme. The lower R.E.R.'s of the swimmers indicates that either the reconversion of lactic acid into glycogen was more adequate during work, or that the muscles were better buffered so that less lactic acid escaped from them during the exercise.

The energy capacities are reported in Table III. The energy yield from the aerobic pathway, reported in cal/kg, between the experimental and control groups was not significant after the training programme. One would expect that the maximal aerobic capacity would not increase in the control group since the controls did not increase their daily activity. The slight increase in the maximal energy yield from the aerobic pathway of the experimental group was an indication of their already partially developed level of cardiorespiratory fitness.

The maximal alactacid energy capacities reported for the subjects in this study were less than those reported by Margaria (1963). The maximal alactacid capacity as

reported by Margaria was approximately 100 cal/kg., whereas in this study it was found to be only 88.7 cal/kg. of body weight after training. Between groups, a non-significant difference was noted.

Likewise, there was a non-significant difference in the maximal alactacid and lactacid energy capacities between the two groups. The same observation was true for both groups when comparing the before and after training values. These values, however, reveal the large energy contribution by the anaerobic mechanism to the total energy production.

Blood lactate concentration is often used to calculate the amount of lactate produced as an index of anaerobic work. According to Linde (1963), when the blood lactate rises above 65 mg.%, the max. $\dot{V}O_2$ has been reached and anaerobic metabolism is being carried out. Therefore, the achievement of this level of blood lactate can be used as a measure of maximal motivation. Trained athletes can achieve higher levels of blood lactate concentration during maximal exercise, probably due to their increased motivation. The state of physical fitness is also demonstrated by the fact that the trained individual can perform more work before the blood lactate

TABLE III
Metabolic Energy Sources
(calories/kilogramme)

SUBJECTS	MAXIMAL AEROBIC		MAXIMAL ALACTACID		MAXIMAL LACTACID	
	B	A	B	A	B	A
C1	175.39	176.43	75.69	83.14	88.02	96.49
C2	183.43	176.74	95.46	71.45	59.25	49.09
C3	193.00	194.67	70.25	88.24	47.40	40.63
C4	216.20	185.92	71.17	73.62	35.54	71.10
C5	239.29	218.71	74.57	104.68	93.10	137.11
C6	179.44	202.74	83.33	92.34	133.73	133.73
C7	229.11	211.98	92.43	100.57	118.49	123.57
C8	146.06	148.01	70.00	67.07	66.02	98.18
C9	174.33	189.45	77.20	83.21	81.11	91.41
C10	191.82	217.07	92.43	110.05	137.11	148.96
C11	171.27	149.57	—	—	—	—
C12	171.45	183.59	82.93	78.64	199.76	165.89
Mean	189.23	187.91	80.50	86.64	96.33	105.11
S.D.	± 26.78	± 23.33	± 9.45	± 14.05	± 47.90	± 40.70
E1	202.03	212.52	81.24	88.42	34.87	64.32
E2	253.15	234.05	100.94	82.40	57.21	72.79
E3	179.41	186.88	68.36	72.00	42.15	64.32
E4	218.70	227.59	98.22	108.12	66.02	55.86
E5	238.65	217.08	84.89	95.51	50.44	64.32
E6	203.32	206.57	74.53	67.54	36.56	55.86
E7	205.24	215.53	98.23	91.43	81.76	81.25
E8	215.59	222.62	89.76	103.63	115.11	76.17
E9	198.17	212.68	80.49	97.17	125.60	—
E10	211.25	204.06	—	87.20	62.80	50.78
E11	143.46	196.88	45.66	83.72	25.39	66.02
E12	212.37	204.34	75.78	87.62	105.29	110.03
Mean	206.78	211.73	81.65	88.73	66.93	69.25
S.D.	± 27.48	± 13.11	± 15.99	± 11.76	± 33.21	± 16.28

C = Control Subject

E = Experimental Subject

B = Before (Pre) Season

A = After (Post) Season

reaches or exceeds 65 mg.%. Eriksson (1971) reports that after heavy exercise in children a low lactate concentration is a common finding. In the present study it was shown that the lactate concentration in exercising muscles at maximal work was low (Table II). However, the subjects in this study were not using their total body mass in the performance of the maximal ergometer test. Therefore, lactate produced by the working leg muscles would diffuse throughout the body, resulting in a low total body concentration.

Exercise heart rate (HR) values for the swimmers were lower at all metabolic levels when compared with the control group. This observation is a well-known characteristic of trained individuals. For a similar increase in O_2 consumption, the control group displayed a greater increase in HR than did the experimental group, which is also in accord with current knowledge.

Åstrand (1970) has stated that there is no significant difference between the maximal HR of trained and untrained subjects. In this study it was found that training did not produce a significant change in the maximal heart rates of the experimental subjects. A non-significant difference was also displayed between the two groups (Table II).

Much emphasis has been placed in the past on HR recovery curves after strenuous exercise as an index of physical fitness. The present study revealed a non-significant difference in the HR recovery curves from maximal exercise, although the control subjects tended, on the average, to have slightly slower heart rate recoveries than the experimental group.

CONCLUSIONS

In conclusion, the lack of statistically significant

change in the maximal oxygen consumption expressed in ml/kg-min. exhibited by the experimental group after the competitive training season reveals the considerable adaptation of the oxygen transport system which is maintained by the 'age-group' swimmers throughout their training programme. At the time of the pre-training evaluation, these girls had just finished very intensive summer training. The long term exercise engaged in by the 'age-group' swimmers had caused adaptation of the oxygen transport system, as revealed by the maximal oxygen consumption, to near peak levels. However, continued training appears to give the ability to come closer to their maximal level of oxygen consumption during swimming and to maintain this level for a longer period of time. The slight increase in maximal oxygen uptake experienced by the experimental group after the training period (47.7 ± 5.2 to 48.8 ± 3.4 ml/kg-min.) may be attributed to growth.

The 13% difference in max. VO_2 (ml/kg-min.) between the experimental and control groups (47.7 ± 5.2 vs. 43.8 ± 6.2 and 48.9 ± 3.4 vs. 43.3 ± 4.8) may be due partially to heredity. However, the difference can most likely be attributed to the adaptation of the oxygen transport system as a result of the long-term heavy physical training programme engaged in year after year by the 'age-group' swimmers.

Based on the results of the present study, it is concluded that girls involved in 'age-group' swimming programmes possess a significantly superior oxygen transport system as compared to untrained girls of the same age. In addition, due to the long-term heavy physical training programme engaged in by 'age-group' swimmers, this high level of aerobic fitness is maintained throughout the year. Therefore, the development of swimming speed in mature trained endurance athletes will depend on the contribution of factors other than aerobic capacity.

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