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The Working Capacity of Toronto Schoolchildren

Part I

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THE Human Adaptability project of the International Biological Programme (I.B.P.) has as one of its objectives the completion of detailed studies of working capacity on substantial populations of primitive peoples, athletes, city-dwellers, and schoolchildren. The parameters that are of interest are summarized in Table I.

It is planned that laboratories from many nations will co-operate in the I.B.P., and in order that results from the various sources may be comparable, much effort has been devoted to the development of internationally accepted standards of methodology.[1, 2] It is also important that the proposed procedures should be both simple and practicable when applied to a substantial population of the type envisaged. Accordingly, an international working party was convened in Toronto in the summer of 1967 with the objective of applying the procedures listed in Table I to a population of schoolchildren aged 10 to 12 years. Details of the methods used are given in an appendix to this report.

Although the prime object of the project was to test the feasibility of detailed medical and physiological investigations in a randomly selected healthy population, the findings have considerable intrinsic interest for Canadian physicians. Relatively few normal values are available for children in this age range, and none have been reported for a survey as comprehensive as that which we have conducted. The findings have an added interest in that the children tested, who were drawn from the Metropolitan Toronto school system, formed part of a larger random sample of 2000 Canadian children on whom measurements of physical work capacity (PWC_{170}) had been completed some months earlier (Canadian Association of Health, Physical Education and Recreation).[3]

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This study was carried out as a Pilot Trial of Procedures for the Human Adaptability Project of the International Biological Programme.

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TABLE I.—PARAMETERS OF WORKING CAPACITY REQUIRED FOR THE INTERNATIONAL BIOLOGICAL PROGRAMME AND MEASURED IN THE PRESENT STUDY

Aerobic power	—Maximum or sub-maximum exercise test
Anaerobic capacity	—Maximum lactate
	—Lactate threshold
Heart size	—X-ray
	—Cardiac output (sub-maximum exercise)
	—Blood pressure (resting)
Hemoglobin	—Total hemoglobin - blood volume
Anthropometry	—Height, weight, skinfold measurements
	—Body density
	—Photography
Muscle strength	—Grip
	—Arm
	—Leg
	—Torso
Selected tests of lung function	—Vital capacity
	—One-second forced expiratory volume
	—Residual volume
	—Total lung capacity
	—Diffusing capacity
General medical examination	

THE POPULATION

Through the generous co-operation of the Provincial Department of Education and local school boards, class lists were obtained for 10 Metropolitan Toronto schools that had participated in the CAHPER survey of working capacity.[3] The names of 80 pupils were randomly selected from grades 4, 5 and 6 of the 10 schools concerned, and letters outlining the proposed tests were sent to the principals and parents. These letters were in the native language of immigrant parents. A stamped and addressed envelope and reply form were enclosed, and where necessary this was followed up by a telephone call. The tests were arranged during the school holidays to avoid interference with studies, and it was also emphasized that the tests would be arranged as a "learning experience" for the children. A free taxi-service was provided to and from the laboratory, and a detailed fitness report was offered if desired. On the other hand, we were careful to maintain the volunteer status of the children. Assurance was given that unwillingness of the child or his parents to participate in the proposed program would not reflect in any way upon his school record, nor would it be reported to the school

TABLE II.—STANDING HEIGHT OF SUBJECTS, CLASSIFIED ACCORDING TO CHRONOLOGICAL AND DEVELOPMENTAL AGE* MEAN AND S.D. FOR EACH GROUP (CM.)

	Boys			*Girls*		
	Chronological age		*Developmental age*	*Chronological age*		*Developmental age*
Group 1. (Chron. age 9-10 years; 0 - ½ second permanent molars erupted; radiol. age 9-10 years)	142.9±6.9	Tooth eruption	143.8±10.3	140.5±6.0	Tooth eruption	141.6±7.2
		X-ray$_1$	140.6±5.1		X-ray$_1$	140.8±5.7
		X-ray$_2$	140.6±5.1		X-ray$_2$	140.5±8.1
Group 2. (Chron. age 11 years; 1 - 3 of second permanent molars erupted; radiol. age 11 years)	146.1±6.8	Tooth eruption	144.4±5.5	149.9±6.4	Tooth eruption	149.1±6.0
		X-ray$_1$	147.3±5.2		X-ray$_1$	142.7±10.1
		X-ray$_2$	145.4±4.4		X-ray$_2$	145.6±2.7
Group 3. (Chron. age 12-13 years; all second permanent molars erupted; radiol. age 12-13 years)	148.2±8.3	Tooth eruption	147.1±6.6	156.6±3.8	Tooth eruption	154.2±7.9
		X-ray$_1$	149.0±9.2		X-ray$_1$	155.5±5.7
		X-ray$_2$	152.2±8.5		X-ray$_2$	156.4±5.6

Mean Standard Deviation for all subjects:

Chronological age $\overline{S.D.}$ = 6.4 cm.
Tooth eruption $\overline{S.D.}$ = 7.3 cm.
Radiological age – X-ray$_1$ = chief radiologist $\overline{S.D.}$ = 6.8 cm.
– X-ray$_2$ = departmental staff $\overline{S.D.}$ = 5.7 cm.

authorities. If the reply of a parent was negative, we simply contacted the next name on the class list. Letters were sent to a total of 200 parents; 70 agreed to the attendance of their children at the laboratory, and 63 of the 70 returned for a second series of tests. The proportion of positive responses was rather higher from suburban than from urban schools, and our final sample may have had a slight bias towards the more athletic children in the class. Parents were questioned regarding the interest of their children in sports; 24 thought this "above average", 35 "average", and only 11 "below average". A sample of those who did not reply to the letter and were unwilling to participate were later questioned by telephone. About 60% claimed that they were out of town at the time of testing (July and August); the remainder gave vague and evasive replies suggesting lack of interest in or understanding of the project.

Experimental plan.—The children attended the laboratory at the same time on two mornings, once in July and once in August. Measurements were made in an air-conditioned room, with the environmental temperature maintained at 70° F. On reaching the laboratory the children were allowed an initial rest period, but no attempt was made to achieve a true basal state.

At the first visit a general medical examination was carried out, and a progressive sub-maximal exercise test was performed on the treadmill, with measurement of the exercise-diffusing capacity. Radiographs were also taken for assessment of heart size (P-A and lateral chest films) and wrist development.

At the second visit standard photographs and anthropometric measurements were taken, skinfold thickness was measured at eight sites and body density was assessed by underwater weighing. The strength of selected muscle groups was tested, various parameters of pulmonary function were measured, a progressive sub-maximal exercise on the bicycle ergometer was completed, and finally the maximum oxygen intake was measured during uphill running on the treadmill.

The total time for which the children were required was approximately two hours at the first attendance and three hours at their second attendance. Groups of four school friends were seen together, and in this way a competitive element was introduced into the exercise and strength tests. The majority were happy and interested in the investigation throughout, but a few were upset by the collection of capillary blood samples for hemoglobin and lactate estimations.

RESULTS

1. *Classification of the Data*

Theoretically, data could be classified in terms of either the chronological or the developmental age of the children. Developmental age has been assessed in terms of (a) eruption of permanent molar teeth and (b) radiological development of the wrist joint. Radiographs of the wrist were appraised both by a member of the depart-

TABLE III.—GRIP STRENGTH OF DOMINANT HAND, CLASSIFIED ACCORDING TO CHRONOLOGICAL AND DEVELOPMENTAL AGE: MEAN AND S.D. FOR EACH GROUP (KG.)

	Boys			*Girls*		
	Chronological age		*Developmental age*	*Chronological age*		*Developmental age*
Group 1. (Chron. age 9-10 years; 0 - ½ second permanent molars erupted; radiol. age 9-10 years)	19.0±2.6	Tooth eruption	21.4±4.0	15.5±3.0	Tooth eruption	16.1±2.7
		X-ray$_1$	18.6±3.1		X-ray$_1$	15.7±2.8
		X-ray$_2$	18.6±3.1		X-ray$_2$	15.4±3.2
Group 2. (Chron. age 11 years; 1 - 3 of second permanent molars erupted; radiol. age 11 years)	21.0±4.7	Tooth eruption	20.0	18.7±4.0	Tooth eruption	18.9±4.6
		X-ray$_1$	20.3±3.2		X-ray$_1$	16.4±3.4
		X-ray$_2$	21.0±2.9		X-ray$_2$	18.2±4.0
Group 3. (Chron. age 12-13 years; all second permanent molars erupted; Radiol. age 12-13 years)	23.3±3.3	Tooth eruption	23.1±2.3	23.1±6.0	Tooth eruption	24.8±5.2
		X-ray$_1$	23.8±4.4		X-ray$_1$	23.1±5.4
		X-ray$_2$	24.3±4.4		X-ray$_2$	22.1±5.9

Mean Standard Deviation for all Subjects:
Chronological age = 3.9
Tooth eruption = 3.8
Radiological age – X-ray$_1$ = Chief radiologist = 3.7
– X-ray$_2$ = Departmental staff = 3.9

mental staff (using Todd's Atlas[4]) and by a consultant radiologist; in general, there was good agreement between the two assessments.

The relative merits of chronological and developmental classifications have been examined in relation to measurements of standing height (Table II) and grip strength of the dominant hand (Table III). In both cases the variance of the data was similar whether the classification was based on developmental age or chronological age; accordingly, the simple criterion of chronological age has been used in all subsequent analysis of the results.

2. *Aerobic Power*

(a) *"Maximum" effort tests.*—Physiological responses to the "maximum" effort tests are summarized in Tables IV and V, with curves for the recovery period in Fig. 1. The figures for arterial

TABLE IV.—PHYSIOLOGICAL MEASUREMENTS DURING "MAXIMUM" EFFORT TESTS ON TREADMILL: MEAN±S.D. OF RESULTS

	Boys (*n* = *23*)	*Girls* (*n* = *24*)
Arterial lactate (mg./100 ml.)	78.7±28.2 (34.5—130.6)	77.1±25.4 (47.4—161.8)
Respiratory quotient	1.08±0.20	1.08±0.21
Maximum pulse rate	193±7	195±7
Maximum ventilation (l./min BTPS)	65.3±13.6	55.6±9.3

lactate following exercise were very close to the average found by Åstrand[5] in studies of Swedish children. The terminal pulse rate, on the

TABLE V.—CLASSIFICATION OF DATA FROM "MAXIMUM EFFORT" TESTS ON BASIS OF ARTERIAL LACTATE CONCENTRATIONS: MEAN ± S.D.

	Directly measured maximum oxygen intake *l./min*	Directly measured maximum oxygen intake *ml./kg. min*	*Error of prediction* l./min*	*Pulse rate*	*Respiratory quotient*	*Arterial lactate (mg./100 ml.)*
Boys — Strenuous effort (lactate 80 mg./100 ml., n = 10)	1.79±0.32	47.9±6.3	0.00±0.32	195+7	1.09±0.16	105.2±18.4
Moderate effort (lactate 60-80 mg./100 ml., n = 6)	1.91±0.29	48.1±5.3	−0.02±0.41	191±8	1.13±0.28	73.0±2.6
Poor effort (lactate >60 mg./100 ml., n = 7)	1.80±0.46	47.9±5.9	+0.17±0.21	192±10	1.03±0.18	47.2±8.0
Girls — Strenuous effort (lactate >80 mg./100 ml., n = 6)	1.43±0.26	38.6±3.9	−0.05±0.12	199±7	1.28±0.22	109.4±31.1
Moderate effort (lactate 60-80 mg./100 ml., n = 13)	1.64±0.34	38.5±4.1	−0.14±0.27	196±8	0.99±0.16	71.9±4.2
Poor effort (lactate >60 mg./100 ml., n = 5)	1.50±0.25	38.9±4.1	+0.02±0.21	195±9	1.07±0.15	51.6±2.6

* The oxygen scale of the Astrand nomogram has been used, taking a pulse rate in the range 150 to 170/min.

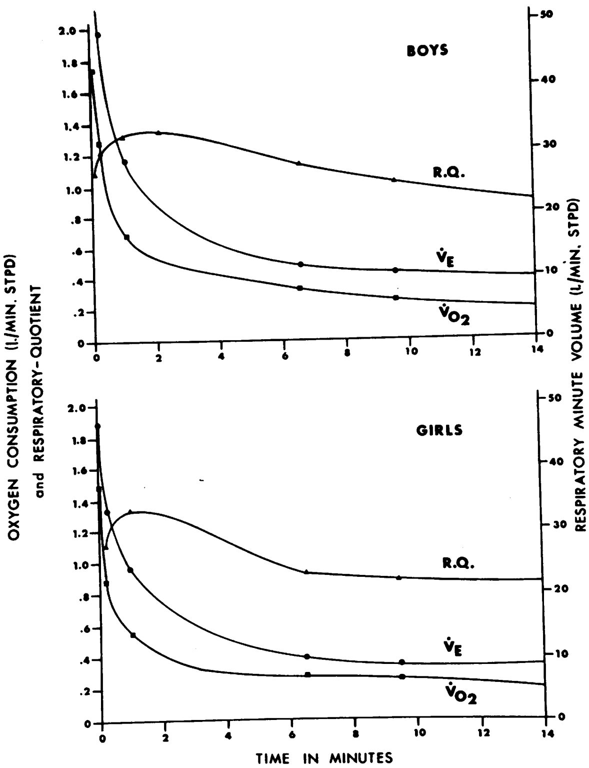

Fig. 1.—Respiratory minute volume, oxygen consumption, and respiratory quotient during period following maximum exercise. Individual points represent mean values for 17 boys and 17 girls. Gas collection periods 0-½ min, 1-1½ min, 1½-3 min, 5-8 min and 8-11 min after exercise.

other hand, was a little lower than that of Robinson,[6] of Morse, Cassels and Schlutz[7] and of Wilmore and Sigerseth,[8] and was substantially lower than the averge of ~210/min reported by Åstrand.[5] Unfortunately we were not able to obtain a good "oxygen plateau" on most of the present sample of children, and it seems likely that at least some gave up running before reaching their true maximum oxygen intake.

When subjects were classified in terms of their arterial lactate two minutes after exercise (strenuous effort, lactate > 80 mg./100 ml.; average effort, lactate 60 to 80 mg./100 ml.; poor effort, lactate < 60 mg./100 ml.), the oxygen intake equalled or exceeded that predicted from the response to sub-maximum treadmill exercise in those making a "strenuous" or an "average" effort, but not in those making a "poor" effort. It should be noted that the predictions were obtained from the Åstrand nomogram,[9] applying age corrections equivalent to a maximum pulse rate of 212 in boys and 207 in girls (18% and 10% respectively). The coincidence of the predicted values with the values actually measured at a much lower pulse rate might suggest that the majority of children making a good or average effort were close to their true maximum; on the other hand, the lower values in those making a poor effort is clear evidence that this last group could have reached a larger oxygen intake if they had tried harder.

During the recovery period, the oxygen consumption showed a rapid return towards resting values. The respiratory minute volume was adjusted more slowly, and both boys and girls reached a maximum respiratory quotient of 1.3 to 1.4 some two minutes following maximum exercise.

(b) *Sub-maximum exercise.*—The maximum oxygen intakes as predicted from the response to sub-maximum treadmill exercise are summarized in Table VI. As we have noted above, the predicted values agree closely with direct estimates of the maxima, and set a lower limit to the probable aerobic power of the population. However, by analogy with the response of adults, it seems possible that predictions based on the first response of an individual to sub-maximum exercise may underestimate his true maximum by ~10%. If this be the case, the upper limit of aerobic power for the population can be set at 51 ml./kg.min for the boys, and 41 ml./kg.min for the girls. These values are substantially lower than the figures reported by Åstrand[5] (56 and 51 ml./kg.min) and Wilmore and Sigerseth[8] (51 ml./kg.min in girls), but are at least comparable with a number of previous surveys in the United States,[6, 7, 10-12] Canada[13] and other parts of the world.[14-16]

Two important variables in the use of sub-maximum predictions are the mode of testing and the number of tests performed. Most previous studies of children have used a bicycle ergometer. Our children were exercised on the

TABLE VI.—PREDICTED MAXIMUM OXYGEN INTAKES FOR SCHOOLCHILDREN, MEAN ± S.D.
(Based on response to sub-maximal treadmill exercise, using oxygen scale of Astrand nomogram, and correcting to a maximum pulse rate of 212 in boys and 207 in girls)

	Boys			Girls		
Age	n	*l./min STPD*	*ml./kg. min*	n	*l./min STPD*	*ml./kg. min*
9 - 10	7	1.75±0.19	49.7±7.9	15	1.23±0.18	36.8±5.2
11	10	1.84±0.32	48.3±7.5	11	1.35±0.13	35.9±5.5
12 - 13	15	1.78±0.34	45.8±6.9	10	1.68±0.30	38.3±7.6
All subjects	32	1.79±0.30	47.4±7.3	36	1.38±0.25	36.9±5.9

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treadmill at their first visit and on the ergometer at their second visit. In general, they seemed less apprehensive during the second series of submaximal tests, and this was reflected in higher values for the predicted maximum oxygen intake (51.2 ml./kg.min in the boys, and 41.3 ml./kg.min in the girls).

A number of authors have expressed their results in terms of a PWC_{170} rather than a predicted maximum oxygen intake; when our data were expressed in this way, the average for the boys was 14.1 Kgm/kg., and for the girls 11.2 Kgm/kg. In both sexes the result was about 10% higher than that reported by CAHPER[3] in their study of Canadian schoolchildren. It is possible that by allowing the children and their parents more opportunity to refuse a test, we may have sampled a fitter part of the population. However, this is unlikely, since our sample was drawn entirely from a metropolitan environment, and was heavier than the CAHPER sample. A number of other points of technique may have contributed to the discrepancy. The temperature of our laboratory was held at 70° F., whereas many of the schools would have been heated to a much higher temperature. All of our tests were conducted in the summer, whereas the season of testing was more variable (and mainly winter) in the larger sample. We made a correction for the weight of the clothing worn by the children, and it is not clear whether this was done in the larger sample. Each of these factors could have contributed to the difference of PWC_{170} reported by the two groups. However, we suspect that the main basis for the discrepancy was that our children had had the experience of a previous visit to the laboratory; in consequence, their physiological response to sub-maximum exercise was less distorted by anxiety, and a higher PWC_{170} was obtained. This view is supported by the similar 10% difference between our first (treadmill) and second (bicycle ergometer) predictions of aerobic power.

Physiological data for the recovery period following sub-maximum treadmill exercise are summarized in Fig. 2. A peak respiratory quotient ~1.2 was reached one minute after ceasing exercise.

3. *Blood Lactic Acid and Oxygen Debt*

As already noted, the maximum lactate levels in the treadmill experiments corresponded closely with those reported by Åstrand.[5] Samples were collected two, four and six minutes after both maximum and sub-maximum exercise, with an additional sample 10 minutes after sub-maximum exercise. In both cases there was a slow decline from the initial reading (Table VII).

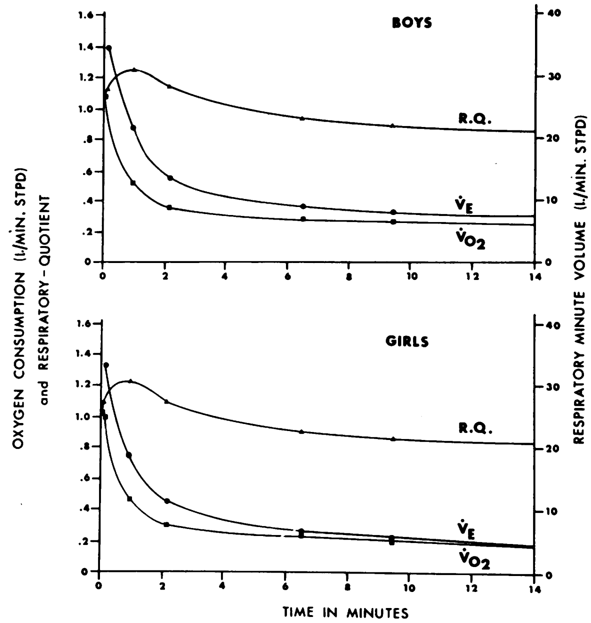

Fig. 2.—Physiological data for the recovery period following sub-maximum exercise on the treadmill. Averaged results for 21 boys and 23 girls. Samples collected 0-½, ½-1½, 1½-3, 5-8 and 8-11 min after exercise.

TABLE VII.—THE COURSE OF ARTERIAL LACTATE FOLLOWING EXERCISE: MEAN±S.D.

Time after stopping exercise (min)	*Arterial lactate (mg./100 ml.)* *Sub-max. exercise*	*Maximal exercise*
2	28.8±11.6 (n=67)	80.1±22.3 (n=35)
4	25.6±11.2 (n=66)	73.3±23.3 (n=35)
6	23.0±10.3 (n=60)	69.9±22.0 (n=14)
10	18.7± 8.3 (n=44)	

This finding corresponds with the respiratory quotient data (Figs. 1 and 2), but differs from our earlier experience with adults[2] where there was no significant difference of lactate concentration in samples drawn two and four minutes after exercise. The decline of lactate concentrations in the children may reflect either the lower peak lactate concentrations that were reached or a more rapid transport of lactate from the leg muscles to the capillaries of the hand. If the latter explanation is correct, then it would seem desirable that in children, samples for the estimation of blood lactate should be collected not later than two minutes following exercise.

Blood lactate was also sampled two minutes following each of four sub-maximum treadmill tests (Table VIII). The slope and speed of the treadmill in these experiments were adjusted to yield oxygen consumptions ranging from 40 to 80% of aerobic power. The mean lactate concentration showed a progressive rise with each

TABLE VIII.—THRESHOLD OF ANAEROBIC WORK
(Samples of arterialized capillary blood collected 2 minutes after 6 minutes of submaximal work)
Mean ± S.D. for 70 subjects

Load	*Pulse rate (per min)*	*Lactate (mg./100 ml.)*	*Oxygen consumption (ml.STPD/min)*	*Aerobic power (%)*
1	138.1	4.6± 3.2	754±178	43.9
2	157.9	5.6± 3.0	964±210	56.2
3	178.2	10.0± 6.2	1177±250	68.6
4	191.8	21.9±11.0	1368±300	79.7

increase of load, but a substantial accumulation of lactate occurred only at the fourth load. The form of the relationship was in keeping with our previous observations on adults,[1] but the absolute levels of lactate at any given fraction of aerobic power were lower in the children.

In the "maximum" effort experiments, the total oxygen debt repaid in the first 11 minutes of recovery was 2.44 1. STPD in the boys, and 1.76 1. in the girls; even when related to body weight, these values are smaller than the maximum oxygen debt of adults.[17] Since blood lactate levels were also lower in children, there seems to be a true physiological difference between children and adults in this respect; however, the short duration of the "maximum" effort tests and a failure to achieve a true maximum in some children undoubtedly contributed to the lower lactate levels. In sub-maximum experiments at 80% of aerobic power, the oxygen debt repaid in the first 11 minutes of recovery averaged 1.87 1. STPD in the boys and 1.40 1. in the girls. When the excess oxygen consumption was plotted semi-logarithmically, and alactate and lactate components of the oxygen debt were distinguished, a fair correlation was found between the lactate debt and the directly measured blood lactate (for the boys, $r = 0.61 \pm 0.14$, and for the girls, $r = 0.64 \pm 0.13$). However, the necessity of collecting expired gas for a further 11 minutes severely taxed the patience of many children, and for most purposes it would seem preferable to estimate lactate levels from a single specimen of blood collected two minutes after exercise.

4. *Heart Size and Cardiac Output*

The heart volume was calculated from posteroanterior and lateral chest radiographs, using the method of Reindell *et al.*[18] The measurements were made quite rapidly by an experienced member of the staff, and the figures obtained correspond closely with those reported by Bouchard, Hollman and Herkenrath[19] for students in Cologne (Table IX). At all ages the average heart volume was larger in the boys than in the girls, but owing to the earlier "growth spurt" by the girls, the difference was most marked in the younger subjects.

TABLE IX.—THE HEART VOLUME (ML.) AS ASSESSED FROM CHEST X-RAYS BY THE METHOD OF REINDELL *et al.*[18]): MEAN ± S.D.

	Boys		*Girls*
Age	*Present sample*	*Bouchard et al.,[19] Cologne*	*Present sample*
9-10..........	349±71	332±52	320±39
11............	382±70	364±41	369±80
12-13.........	401±86	394±49	398±70
Entire sample..	379±77		356±69

The heart volume was significantly correlated with maximum oxygen uptake in both boys and girls, the respective prediction equations being:

$$\text{Boys}: \dot{V}_{O_2} \text{ max } (1./\text{min } STPD) = 0.0298 \pm 0.0054 (HV - \overline{HV}) + 1.76 \pm 0.04;$$

$$\text{Girls}: \dot{V}_{O_2} \text{ max } (1./\text{min } STPD) = 0.0227 \pm 0.0049 (HV - \overline{HV}) + 1.41 \pm 0.03$$

where HV is the observed heart volume and $\overline{HV}$ the mean heart volume for the group.

Neither of the two techniques used for the measurement of cardiac output was easy to perform on the children, and much time was lost in teaching the desired pattern of rebreathing. Partly because the children were seated on a bicycle ergometer, and partly because it was their second visit to the laboratory, more consistent results were obtained with the CO_2 rebreathing than with the acetylene rebreathing procedure. Since the latter has been evaluated on adults[1, 2] only the findings for the CO_2 rebreathing method will be described in detail. This method required an estimate of the arterial P_{CO_2}, since the literature contains no information on the dead space of children during maximum exercise. Wide oscillations of end-tidal CO_2 tension were commonly seen, and the most reliable procedure for the estimation of arterial P_{CO_2} was found to be application of the Astrup technique to arterialized capillary blood samples; prolonged warming of the finger tips was necessary to overcome the vasoconstriction induced by exercise.

Measurements of cardiac output were obtained while cycling at two submaximal loads (generally 40 and 70 Watts, 240 and 420 Kgm/min). The average cardiac outputs at these two loads were 6.5 and 7.4 1./min, corresponding to arteriovenous oxygen differences of 10.1 and 13.3 ml./100 ml. respectively. The stroke volume was closely similar at the two loads, averaging 46.2 ± 12.7 ml., with a difference of 2 ml. between boys and girls. Assuming that the children had reached their maximum stroke volume, their maximum cardiac output while cycling would thus be a little under 10 l./min for a total body weight of 39 kg.; this does not seem greatly out of line with the figure of 25.6 l./min we have found in young men with an average weight of 75 kg.[2]

As would be anticipated in young children, the "casual" sitting blood pressure was not remarkable, the average figures being 107.5 ± 11.1 mm. Hg (systolic) and 67.5 ± 8.2 mm. Hg (diastolic).

5. *Hemoglobin and Blood Volume*

Hemoglobin averaged 14.1 ± 1.1 g./100 ml. in the boys and 14.1 ± 0.8 g./100 ml. in the girls; these figures correspond closely with the findings of Mugrage and Andersen (1936) as cited by Tanner[20] and with the more recent studies of Elwood, Withey and Kilpatrick[21] in the United Kingdom.

An attempt was made to measure blood volume and total hemoglobin by a rapid procedure involving the breathing of 0.1% carbon monoxide for eight minutes. Unfortunately the increase of back pressure was small, and the rebreathing procedure was of marginal accuracy for the necessary analyses. The mean blood volumes obtained (114 ± 32 ml./kg. in the boys, 112 ± 30 ml./kg. in the girls) were at least 30% larger than in most previous series.[5, 7, 22] Similar difficulties were encountered when the rapid procedure was later extended by one of us (R.J.S.) to adults. However, quite acceptable results could be obtained if the period of carbon monoxide inhalation was extended to 15 minutes. It is probable that an equal period of carbon monoxide inhalation is needed to obtain reliable results in children, but children might not tolerate a further protracted period of mouthpiece breathing in an already lengthy series of investigations.

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