Working Capacity of Normal Children Tested on a Bicycle Ergometer

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ABSTRACT

Working capacity defined as that work load performed at a minute pulse rate of 170 was determined in 200 school children aged 6 to 16 and in 40 young adults. Working capacity increased gradually with age and was greater in boys than girls at all ages. The range of normal was large. Working capacities of 11- and 12-year-old Winnipeg children in kg./M./min. were 384 for boys and 300 for girls, these values being 19 and 14% below comparable studies from California and Sweden. Working capacities of Winnipeg student nurses averaged 478 kg./M./min., half the value reported for nurses from Sweden.

THE evaluation of disability produced by cardiac disease poses many problems. This is not only true for adult patients where compensation, emotional factors, fear of physical activity, poor general physical fitness, and lack of physical stresses in everyday life are factors to be considered, but also is true for children in whom the history, especially that obtained from well-meaning parents, may be inadequate and misleading. This has led to the development of various exercise tests designed to tax the cardiovascular system. The bicycle ergometer has several advantages over other forms of exercise; this is especially so in children, for it is hoped that they are accustomed to this form of activity. Prior to the evaluation of exercise tests in children with cardiovascular disease, it was necessary to study a group of normal children. Much has been said about the lack of physical prowess of the average North American child, so that while results were available from Sweden for normal children using the same test methods, it was desirable to collect similar data on Canadian children.

SUBJECTS

The studies were performed during the spring months of 1961 and 1962 and the fall of 1961. One hundred and twelve children, five male and five female in each age level from 6 to 16 years from 10 schools in the city of Winnipeg, were studied. The subjects were selected by the class teacher, who was instructed to send five students: three who were considered to be of average physical ability, one better than average, and one poor in this regard.

A more detailed study was then carried out on 88 grade 6 students, aged 11 and 12 years. In this study all members of four classes were exercised. Classes A, B and C were from public schools where only two 30-minute periods of physical education were allotted each week. Class C was from a school in a low-income area, classes A and B from a high-income area. Classes B and C were average grade 6 classes while class A was a "major-work" class composed of students from three schools selected for outstanding scholastic ability and learning capacity.

Class D (boys only) was a grade 6 class from a private school where facilities for sports and recreation are superior, and where, in addition to two physical education periods weekly, all students are required to participate in two competitive games periods, and where, as well, most students participate in extra team sports that are organized by the school. For comparison purposes the working capacities of a group of medical students, nurses, and student nurses were also studied.

The initial study was carried out from 3 to 5 p.m. at the hospital. The later studies with the grade 6 students were performed in the schools. Excluded were all children with a history of cardiovascular disease, and any individual with a current or recent respiratory infection.

METHODS

The subject was seated on the bicycle ergometer and the seat was adjusted so that the leg was in a position of nearly full extension when the pedal was at the lowest part of its excursion. The bicycle used was that designed by Holmgren and Mattsson,[1] with an electronic brake. This allows an accurate setting of the resistance loads over a wide range of values, and also has the advantage of making the working load independent of minor fluctuations in the rate of pedalling.

The resting pulse, blood pressure and respiration were recorded, and a brief examination of the chest was carried out. The subject then commenced pedalling, keeping the rate between 60 and 70 revolutions per minute. The work was maintained for 18 minutes, the load being increased at six and 12 minutes of exercise. For 40 subjects, four consecutive six-minute periods were used instead of three. An attempt was made to make the work

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load for the final six-minute period just about the maximum that the subject could comfortably maintain. All children were encouraged to get through the final six minutes regardless of the pulse rate produced.

In all subjects a pulse rate of over 170 per min. was reached. The maximum working capacity[2] is defined as the work load when the pulse rate is 170 beats per minute. This was determined for each subject by plotting the work load *versus* the pulse rate on graph paper. The observed points were connected and the work load where the line crossed the pulse rate level of 170 was taken as the maximum working capacity.

Heart rate was determined by auscultation at the cardiac apex for 20 to 30 seconds at two-minute intervals. The observers' accuracy was checked by an electrocardiogram during the early stages of the study and proved to be within 2%. Respiratory rate was determined by tracheal auscultation. Blood pressure was obtained by auscultation during the fourth minute of each work load. Pulse and respiration were also recorded at one, two and five minutes after the exercise.

RESULTS

TABLE I.—WORKING CAPACITY BY AGE—BOYS

Age	*No. of subjects*	*Height cm.*	*Weight kg.*	*Surface area M.²*	*Working capacity kg./M./min.*
6	5	114	23	.87	270
7	5	130	26	1.02	340
8	5	132	30	1.05	457
9	5	139	34	1.15	435
10	5	139	34	1.13	458
11	5	142	34	1.18	474
12	5	146	40	1.28	533
13	5	150	42	1.32	645
14	5	160	52	1.52	772
15	5	170	61	1.69	739
16	5	172	66	1.81	972
20-30	10	179	78	1.96	964

Mean values for maximum working capacities for the initial all-age study are presented in Tables I and II. There was a gradual rise in maximum working capacity with increasing age. The working capacity for the boys was consistently greater than that for the girls. This was true even for the youngest age group. An exception occurred with the 11 year olds, but a subsequent study of larger numbers of 11-year-old children showed that the boys had working capacities 20% greater than the girls (Table III).

TABLE II.—WORKING CAPACITY BY AGE—GIRLS

Age	*No. of subjects*	*Height cm.*	*Weight kg.*	*Surface area M.²*	*Working capacity kg./M./min.*
6	5	117	21	.83	220
7	5	125	25	.95	250
8	5	133	33	1.11	312
9	5	133	29	1.04	309
10	5	144	30	1.09	329
11	5	147	43	1.29	497
12	7	151	45	1.37	436
13	5	152	42	1.34	336
14	5	161	63	1.64	497
15	5	161	49	1.50	489
16	5	159	54	1.54	621
18-25	21	162	58	1.59	478

There was a high correlation of the working capacities of the boys with their height (.865), weight (.897) and surface area (.904). These correlation coefficients were not as high in the case of the girls, being .658 for height, .696 for weight and .683 for surface area.

The working capacities of the nurses were less than those observed in the 15- and 16-year-old girls. In contrast, the medical students performed as well as the 16-year-old boys.

The mean working capacities of the grade 6 classes are recorded in Table III. For the boy students the age, height, weight and surface area were the same for each group. The mean maximum working capacities were the same in classes B and C, which were composed of the average students. The maximum working capacity for the male academic class was 8% lower than for the average classes, but this difference is not significant. The maximum working capacity in the private school class was 13% higher than that of these average classes, but with the small number of students studied and the large individual variations this difference was also not of statistical significance. In the girl students, the working capacity of the academic class (A) was 16% less than that of the average class (B) in the same school, and this difference is of significance. The two average classes (B and C) had similar working capacities. The mean working capacities of the boys were all higher than those of their female classmates.

TABLE III.—WORKING CAPACITIES—GRADE 6 CHILDREN

	Boys					*Girls*				
Class	*Height cm.*	*Weight kg.*	*Surface area M.²*	*Working capacity kg./M./min.*	*No.*	*Height cm.*	*Weight kg.*	*Surface area M.²*	*Working capacity kg./M./min.*	*No.*
A	146 ± 4*	39 ± 5	1.25 ± .09	432 ± 99	8	148 ± 4	39 ± 5	1.28 ± .10	323 ± 73	13
B	145 ± 9	37 ± 7	1.22 ± .14	472 ± 88	13	139 ± 6	34 ± 7	1.16 ± .12	393 ± 101	15
C	147 ± 5	37 ± 6	1.23 ± .11	468 ± 107	10	154 ± 4	46 ± 8	1.41 ± .13	379 ± 105	9
D	144 ± 5	37 ± 4	1.22 ± .07	531 ± 99	20					

*Standard deviations.

A vs. B $p < .4$
C vs. D $p < .2$
B vs. D $p < .2$

B vs. B $p < .05$
C vs. C $p < .1$

A vs. B $p < .05$

DISCUSSION

Maximal work tests are not suitable for clinical use because they demand an all-out effort by the subject. The end point is partly dependent on will-power and determination, which vary tremendously from subject to subject. Furthermore, tests of this nature would be hazardous for cardiac patients. For this reason the exercise tests used in clinical work must be based on a standardized submaximal work load.

The object of any work-test is to increase the oxygen requirement of the subject. The two most reliable measurements of cardiorespiratory function during a work-test are measurements of oxygen consumption and cardiac output. Oxygen consumption measurements are easy to obtain, but are time-consuming and involve discomfort to the patient caused by breathing into a mask or mouth-piece. Cardiac output measurments are still too complicated to be used in the routine study of a large number of patients. Several investigators[4-7] have shown that there is a high correlation between pulse rate and oxygen consumption during various forms of exercise. For this reason the pulse rate, which is easily measured, has been chosen as the physiologic parameter for following the patient during the work-test.

At high pulse rates, the diastolic filling time of the heart is reduced, and theoretically a point will be reached when the pulse becomes so fast that stroke volume cannot be maintained. When this occurs, the oxygen debt increases, blood lactic acid rises sharply, and the work cannot be maintained. The maximum pulse rate that healthy individuals can sustain varies somewhat with age. Astrand[8, 9] found that in children this varied from 200 to 215 beats per minute. In the young adult it varies from 185 to 200 beats per minute. It was found by Wahlund[2] and Sjöstrand[3] that at a pulse rate of 170 per minute, healthy individuals can do more work than those with cardiorespiratory diseases. This pulse rate could be maintained without too much discomfort by the subjects when exercising. At this pulse rate the oxygen consumption was about 80% of the maximum. Thus, if the subject is exercised until the pulse reaches 170 beats per minute, he is performing work at about 80% of the maximum of which he is capable. This measurement is for the average individual and was determined on adults.

Many of the subjects exercised in this study were able to maintain pulse rates of from 190 to 200 without any undue discomfort, and one girl was studied in whom a pulse rate of 220 beats per minute was sustained for 10 minutes without any discomfort at all. In such subjects, the selection of a work load sufficient to produce a pulse rate of 170 will clearly underestimate the true maximum working capacity.

Realizing these limitations, we have chosen the expected work load that would be performed at a pulse rate of 170 to indicate "maximum" working

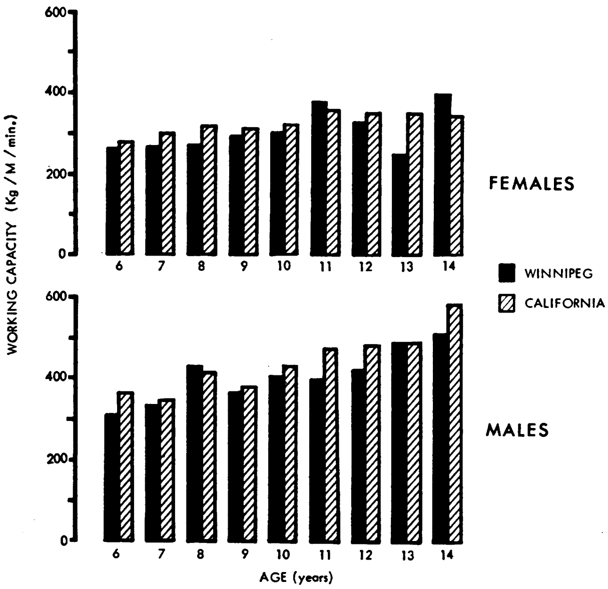

Fig. 1.—Comparison of working capacities in kg./M./min./M² of Californian and Winnipeg children.

capacity in order to compare results with those of other investigators. The term "maximum" as used by Wahlund refers to the maximum that can be maintained in a steady state.

Wahlund[2] and Sjöstrand[3] reported that pulse rate is as accurate an index of working capacity and physical fitness as other more complicated measurements of maximum oxygen uptake and cardiac output. The pulse-rate test is based on the simple fact that the well-trained individual is able to perform a given work load at a lower pulse rate than the untrained individual. Training in any one subject is associated with a reduction of the pulse rate for a given work load.[14] That the well-trained athlete has a slow pulse rate is a well-known fact. There are probably many other factors that should be measured in addition to the response of the pulse rate to the work load, but this measurement has the advantage of simplicity and ease of comparison of one group of subjects with another.

A statistical comparison of our results with those of other studies has not been attempted because of the small number of children tested in the present series. The mode of selection of the children for the all-age study was not a random one, and was adopted to give an indication of the range of values encountered in a normal group without resorting to large numbers. The mean working capacities of 11- and 12-year-old boys was 470 kg./M./min., and of girls of the same age was 386 in the groups where the whole class was studied. The capacities of boys and girls of this age in the initial study where the class teacher selected the subjects were 504 and 417 kg./M./min., respectively. The values in the "selected" group are probably higher than the true class average.

In Fig. 1 the mean working capacities in Winnipeg boys is compared to those of California boys as determined by Adams, Linde and Miyake.[10] It was noted that the heights and weights in the

California children were greater than those of the Winnipeg children. Because working capacity is proportional to body size, the observed capacities in kg./M./min. were divided by the surface area for each group so that a more valid comparison could be made. With the exception of the 8- and 13-year-olds, the working capacities of the California boys are greater than those of the Winnipeg children. A similar comparison for the girls is presented in Fig. 2. With the exception of the 11- and 14-year olds, the working capacities of the California girls in kg./M./min./M^2 body-surface area were greater than those of the Winnipeg girls. None of these differences are large, however.

TABLE IV.—MEAN WORKING CAPACITY IN KG./M./MIN./M^2. BODY SURFACE AREA: 11- AND 12-YEAR-OLD CHILDREN

	Boys		Girls	
	Number	*Working capacity*	*Number*	*Working capacity*
California[10]	30	474	32	348
Stockholm[11]	46	475	30	354
Winnipeg (Class B and C)	23	384	24	300
Winnipeg (Class D)	20	450	—	—

A further comparison of this nature is made in Table IV, with the 11- and 12-year-old children. More importance can be attached to this comparison because these students were not selected. Again, to obviate the differences in body size, the working capacities are expressed per M^2 body-surface area. It is to be noted that in Table IV the mean working capacities are similar for the children of California and Sweden. The working capacities of the Winnipeg boys were 19% below those of the Californians, and the Winnipeg girls 14% below the Californians. Also the private-school Winnipeg boys do not have working capacities equal to those of the Californians.

The largest differences occur when the working capacities of nurses in Sweden, as determined by Bengtsson,[12] are compared to those of Winnipeg nurses. The means of the working capacities were 823 kg./M./min. for the Swedish nurses and 478 for the Winnipeg nurses. Young male adults in Sweden averaged 1136 kg./M./min. compared to 964 for a comparable group in the present study.

Some studies from Sweden[12] have reported that up to age 12 there was no sex difference in the working capacities of children, after which time the working capacity of the boys became greater. The studies of Adams *et al.* on Californian and Swedish children[10, 11] showed that the boys were able to do the same work load at a slower pulse rate from age 6 onward; this was the earliest age studied. This higher working capacity of boys from an early age was also confirmed by the present study.

The number of children tested in this study did not permit an analysis with respect to the effect of physical training on the working capacities of the children. Adams *et al.*[11] in the Swedish study found a definite correlation between working capacity and the degree of physical training in their children. It could be argued, however, that those with naturally high working capacities are those who take part in athletics. In this same study from Sweden, children tested in the spring were retested after the summer vacation. The majority of those with low initial working capacities in the spring showed definite improvement when restudied.

In the present study the working capacity of children from two areas of the city were similar. In one area all of the children possessed bicycles; in the other only 30% had bicycles of their own. Many of the latter group did not own skates and did not attend any community or winter clubs, whereas the children in the other area had many of these benefits. This would suggest that activities must be organized and exercise done under supervision with some effort at physical education to achieve an improvement in physical working capacity. The mere presence of facilities would not seem to be of value if these facilities are considered as playthings only. In a study of Philadelphia children[13] it was found that there was a significant difference between children studied in two different areas of that city. The higher physical working capacity of the boys attending a private school in the present study may be due to factors other than the physical education program in that school, and demands further study before any conclusions are possible.

Several points requiring further investigation have arisen out of this preliminary study. The first and most difficult matter is to assess the relationship between working capacity as determined by pulse rate and physical fitness, especially in view of the fact that the latter term defies exact definition. Climatic and seasonal factors may be of importance in any study, particularly in an area having such clearly defined winter and summer seasons as Winnipeg. The contribution of organized physical training during school hours to the physical fitness of the children is an important topic because an increase in this time is being urged currently. This increase is being opposed by those who believe that school hours should be devoted to intellectual activities, and sports and games should be encouraged outside the school. It would appear that most children are active in play, and it is doubtful that an hour or two of light exercise makes any significant contribution to physical fitness. Many of the schools in California and Sweden have daily periods of physical education, compared to the two 30-minute sessions a week in the Winnipeg elementary schools. In the Winnipeg Public Schools system there is little inter-school competition at the elementary level. Most of the physical education is conducted by the class teachers who have not had sufficient training in this field. There are many small neighbourhood schools, and it is seldom that a child has more than a mile to go to school. Many are brought to school in automobiles, even for the short distances involved. A few ride their bicycles to school, but in present traffic conditions this is hazardous and not encouraged. Gymnasium facilities are not adequate and swimming is not available in schools. Thus, while many boys are active in sports, it is usually the same boys who go in for all the sports, leaving many who do not participate. Girls for the most part do not engage in anything resembling athletic training in the elementary schools. The severity of the cold during much of the winter saps what little incentive exists in those who are not particularly keen on winter sports. All of these factors may contribute to the finding that working capacity in Winnipeg children is less than that of the children in some other areas.

SUMMARY AND CONCLUSIONS

The physical working capacity in 200 normal school children was determined on a bicycle ergometer by the pulse rate method, accepting a work load that produces a minute pulse-rate of 170 as the maximum working capacity. Preliminary observations suggest that the working capacity of Winnipeg children is slightly lower than that of children studied on the same type of bicycle in Sweden and California. Possible reasons for this are discussed. Working capacities of children of high academic standing tended to be lower than average. Working capacities in a group of private school children exposed to more physical training tended to be higher than average. Further study is needed before definite conclusions are possible, because individual variations are large and the differences observed are of low statistical significance. Working capacity of nurses in the present study were 42% lower than those in a comparable group from Sweden.

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