APPLICATION OF A NEW ERGOMETER TO DEVELOP A LABORATORY TEST FOR WORK CAPACITY

WITH FURTHER APPLICATION TO COMPARISONS OF TEN-YEAR-OLD CHILDREN IN LONDON AND SYDNEY*

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PRESENT-DAY ERGOMETERS AND THEIR DEFECTS

Human ergometers in the past have developed through a number of stages, from that devised by Martin (1914) to that of Hudson, Boys, and Williams (1953).

The ergometer (Fig. 1) measures the work done against a resistance according to the formula— $\text{Work} = \text{Force} \times \text{Distance}$. When the wheel is turned in the direction indicated by the arrow, the weight is lifted and the reading on the spring balance is decreased. In theory, if the balance reads B pounds and the weight is W pounds, the force resisting the turning of the wheel is $(W - B)$ pounds. The distance traversed in any given run is $R \times C$, where R is the number of revolutions and C is the circumference of the wheel in feet. The work done in foot pounds is then $(W - B) R.C$. In practice, however, the coefficient of friction of any band alters substantially from day to day according to temperature and humidity and from minute to minute in use. Consequently, standardization and prediction are impossible.

FIG. 1.—Martin ergometer for measuring human work capacity.
S.B. Spring balance.
F.B. Friction band applied to rim of wheel.
W. Weight.

All modern ergometers have been based on some electrical principle, with resulting increase of complexity and cost, but none has solved the problem of securing an accurate constant resistance, or of obtaining the result quickly. Even the best types, such as that described by Kelso and Hellebrandt (1934), still depend on the recording of some graphical area which must subsequently be measured, e.g. by means of a planimeter. This requires a substantial period to determine the result of each experiment—perhaps 15 minutes or so.

The new ergometer employs a device which simplifies construction, greatly refines the accuracy of measurement, and saves time in calculation. This device provides the means of automatically maintaining constant the resisting force or load initially decided upon for any given experiment. This ergometer is described more fully in Appendix A (Fig. 7, page 177).

APPLICATION OF THE NEW ERGOMETER TO TESTS FOR WORK CAPACITY

The time chosen for each test was 15 seconds, since 10 seconds is too short to give sufficiently accurate results and 20 seconds is too long to permit the necessary repetitions without deterioration of performance.

Since the number of repeated muscular contractions may lie between twenty and forty, the tests measure something intermediate between strength and endurance. Since this is not an individual study but one of groups, no particular advantage is secured by dividing performance by body-weight for individual comparisons. Although this was actually done in all cases and many analyses were made of the data so obtained, these are not relevant to the present communication.

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Five desiderata led to the use of the present ergometer for tests of work capacity:

(1) To develop tests which could be carried out within the laboratory in contrast with those which had been used in the field and were dependent upon unusual facilities and good weather.

(2) To ensure that such tests involved more than one or just a few muscular contractions, in order to avoid the drawbacks inherent in most previous laboratory tests such as the hand grip, Sargent high-jump, etc.

(3) To enable the apparatus to be modified easily and quickly for use on either of the major muscle groups in the body: those concerned with powerful movements of the lower limbs, and those concerned with powerful movements of the upper limbs (involving the arms and shoulders).

(4) To utilize such tests in comparing subjects in different places. It was therefore necessary to ensure that the apparatus could be readily transported.

(5) To obtain a result quickly, since the proposed research would necessitate thousands of repetitions, including rehearsal runs, and preliminary and final tests. With the present device, the number of revolutions is read on the revolution counter when the test is finished, and this is simply multiplied by the value of the resistance and then by a constant factor to give the complete result in foot pounds.

In testing the lower limbs a simple construction like the ordinary bicycle ergometer was used, modified by the automatic device for securing constant resistance. The length of each crank was $6\frac{1}{2}$ ", and the flywheel was 21" in diameter, weighing 78 lb. and spinning 2.56 times with each complete turn of the driving wheel.

In order to convert the apparatus to one suitable for testing the upper limbs, one bicycle pedal was unscrewed, and a freely rotating handle was screwed on in its place so that the "pedals" could be turned as in a mangle, wringer, or cranking mechanism. In practice, the child stands stooping towards the bicycle with feet planted well apart, and steadies himself by grasping firmly the nearly vertical part of the bicycle frame about opposite his left shoulder. He is then in a firm position to rotate the bicycle crank with all the force and speed he can muster. All subjects worked with the right arm only, as it was not possible to use the left arm advantageously. The left-handed subjects are penalized, but it is highly improbable that the group comparisons could be affected.

For purposes of safety a large circular shield was securely placed between the rotating handle and the crank arm normally carrying the pedal. This obviated the possibility that the operator's hand might slip and be damaged by the chain gear. In all the thousands of actual tests no untoward happening of any kind occurred.

COMPARABLE GROUPS OF CHILDREN IN LONDON AND SYDNEY

The Departments of Education in both cities advised that the 10-year-old group was the best to work with. Above that age children leave the primary school and are separated into groups according to type of education, and below that age co-operation and determination might not be quite so good.

Again, as a result of advice from the Departments of Education in London and Sydney, two schools in each city were selected as representing children from favourable areas (from the parental and social points of view) and two schools as representing children from congested areas.

In the following Figures the groups from the favourable areas are designated by the letter F and those from the congested areas by the letter C.

These schools yielded well over 300 children for London and nearly the same for Sydney. The proportions F to C were much the same in the two places.

In addition an opportunity was afforded to test the boys in an English public school,* Dulwich College, and a Sydney private school,* Knox College.

The parents of the Knox College boys, who represent a more distinguished and materially successful group than those of the children at the schools already classed as favourable, are represented in the Figures by F+. The parents of the boys at Dulwich College represent a still more selective class, and this group is designated by F++.

A group of Sydney girls corresponding to the Knox College boys and given the symbol F+ was tested at the Presbyterian Ladies College, Pymble (P.L.C.). In fact, in many cases, the children attending Knox and P.L.C. came from the same homes.

Children from two additional Sydney schools were also tested; since the general status of these schools was intermediate between F and C just mentioned, they are designated by the letter I (Table I, opposite).

An invariable rule was that all the 10-year-old children on the roll of the school were tested, the only exceptions being absentees or those ineligible through crippling or injury. These were very few in all. In all cases the tests were carried out in comfortable conditions, neither too warm nor too cold, and in all cases excellent working conditions were provided by the schools in question.

*In spite of the opposition of titles these schools correspond in the two cities concerned. They are regarded as more selective than those administered by the Departments of Education in these countries.

TABLE I
GRADING OF SCHOOLS

City	London	Sydney
F++ Favourable F+	Dulwich College (boys) Oxford Gardens Franciscan	Roseville (mixed) Wahroonga (mixed) Knox College (boys) P.L.C. (girls)
I		Names not given.
Congested	Sleaford Deptford	Redfern Burke Street

ADMINISTRATION OF THE TESTS AND RESPONSE OF THE CHILDREN

In such tests the result with any one child will vary with the load imposed. To obtain a highly accurate assessment of any individual a series of trials would have to be made to discover the optimum load. Fortunately, the optimum in such tests resembles a plateau rather than a peak and closely concordant results are obtained over quite a range of loads. Hence, it was found that in three well-adjusted trials this optimum was approximated even more closely than required in a group study.

The execution of the test was demonstrated to a group of about eight to ten children and then each was given a rehearsal trial in turn, choosing initially a load appropriate to the weight of each child.

Each test lasted 15 seconds, and was started by the signals—"get ready—go", and stopped by corresponding signals. By recording the results of the rehearsal run, the weight was made nearer the optimum in the first trial run—e.g. it was increased if the number of revolutions of the bicycle wheel exceeded a certain value, and decreased if the number was below a second set value. Preliminary work had established that optimum performances were made within the range of 55 to 65 revolutions for the leg test, and 60 to 80 revolutions for the arm test. This, of course, does not represent rate of limb movements, because of the gearing of the bicycle.

To bring the rates of limb movements within these ranges, a second trial run was made, generally with a further small adjustment of the load. The score was taken as the better performance of the two trials. In most cases the second test was the better. If by some mischance the second test fell distinctly below the first, a third trial was given with an intermediate load. When this happened it was generally due to a misjudgment—increasing or decreasing the load too much. In most such cases the best result was obtained with this third trial. It was found that such repetition of trials with a

reasonable rest between, entailed no perceptible fatigue, and in fact almost universally the children would plead to "have another go".

INSTRUCTIONS TO THE CHILDREN.—From the outset the writer was aware that differences in performance might result from differences in the conduct of the tests. It was not considered necessary to adhere to a rigid verbal formula for the instructions, but each child was encouraged to put forth his greatest effort.

This latter procedure called for a good deal of extempore stimulating and encouraging remarks, and in general quite a good deal was spoken to the child. Any attempt to replace this by a set of stereotyped instructions would cause the loss of this personal value and would, in the opinion of the writer, yield inferior results. The following gives the general tenor of the instructions:—

(1) *Practice Run.*—You have seen X do this test and I want you all to have a try in turn. You don't need a saddle, you just stand up, like the racing cyclists do—when they race their fastest. This first "go" will not count—it is to help you get used to the machine. I will ask—"Are you all set?"—to start with, and if you say "Yes", I will then say "Get ready—go". I will stop you by saying "Get ready—stop". You can stop at once just as you saw X stop—and don't move again until the flywheel runs down.

(2) *First Trial.*—Now this is a competition: we all want to see how fast you can ride. The result shows up on the little revolution counter, and I will read it out to you all. Remember you all have an even chance because the small ones ride against smaller weights and the big ones against bigger weights. Now stand in a half circle so that you can all see every try as you wait your turn.

(3) *Second Trial.*—You are each given one more try. If this result is better than the last it will count as your score—so make up your mind to try harder and make that wheel go round still faster. Grip those handles tight and put everything you've got into it.

POSSIBLE FACTORS AFFECTING RESULTS.—At the very outset it was considered possible that certain individuals might be favoured in the tests due to some kind of specific experience.

In order to investigate these aspects thoroughly an assessment was made of each child's experience in using a bicycle or tricycle, in working with a wringer or mangle, in walking upstairs to flats four and five stories high, and in swimming. The results were carefully evaluated by assigning appropriate numbers for each grade of experience. It was found that none of these experiences had any perceptible relationship to the results of the tests.

TABLE II
HEIGHTS AND WEIGHTS

Sex	Boys				Girls			
Cities	London		Sydney		London		Sydney	
Groups	Height (cm.)	Weight (kg.)	Height (cm.)	Weight (kg.)	Height (cm.)	Weight (kg.)	Height (cm.)	Weight (k.g)
F	140	31·1	140	33·5	140	31·8	140	32·6
C	136	30·7	136	30·4	135	29·5	135	30·1
Mean	138	30·9	138	31·9	137	30·6	137	31·3
F+	143	34·0	143	33·8	—	—	—	—

COMPARISON OF RESULTS

Height and Weight

Boys.—Surprisingly little difference was found in physical dimensions between boys from the two cities (Table II).

The agreement is within a centimetre in height in each of the pairs of schools selected—136 cm. for both C groups, 140 for both F groups, and 143 for the F+ groups.

The Sydney boys averaged about one kilogram heavier than the London boys; since this did not affect the main object of the research no analysis was made for statistical significance.

GIRLS.—Much the same relationships in body dimensions were found for the girls, heights being nearly identical in the corresponding C and F groups, and the Sydney girls being a little heavier (Table II).

Performance

In Figs 2 and 3, the mean performance for each group is calculated as a percentage of that for the best group. The results are then represented by a series of rectangles arranged in order, descending

from the 100 mark. Each such rectangle is labelled by the symbols already explained—F++, F+, F, I, and C. The Sydney results are shown by the clear rectangles, the London results by the shaded rectangles. The research centres in the comparison of the F and C groups for London and Sydney, but the other results are included for further interest.

Boys.—Fig. 2(a) establishes that in the case of the 10-year-old boys (arm test) the whole Sydney group is well in advance of the whole London group.

The F London group is about 25 per cent. lower than the F Sydney, and even the F++ London is about 20 per cent. lower than the F+ Sydney. The C London is about 10 degrees below the C Sydney.

In the leg test for boys (Fig. 2b), there is again a distinct superiority of F and F+ Sydney, as against F and F++ London, but the difference between the C groups is not significant.

When the results of the arm and leg tests are taken together* the F Sydney groups show a clear superiority over the F London groups (Fig. 2c).

For calculation see Appendix B

FIG. 2.—Relative performances (boys).

The combined results of the C groups were compared statistically, and it was found that the superiority of Sydney boys was established at the probability level 0.05, *i.e.* the odds against its occurrence by chance are 20 to 1.

GIRLS.—Fig 3 (a) shows that, in the arm test, as with the boys, the F Sydney groups are about 18 per cent. ahead of the F London group. Although C Sydney appears to be somewhat ahead of C London (5 per cent.) it was necessary to investigate the results statistically, and this showed that the superiority is not so well established, being only about 7 to 1 in favour.

Fig. 3 (b) also, as in the case of the boys, shows a considerable superiority in the leg test of F Sydney above F London—a little more than 12 per cent., but the small graphical superiority of C Sydney over C London is not significant.

Consequently, when the arm and leg tests are considered together (Fig. 3c) for an overall comparison of work capacity, although the F Sydney group shows a considerable superiority over F London, the C groups are not significantly different.

COMPARISON OF THE F AND C GROUPS.—As may well be expected, both in London and in Sydney the F groups performed much better than the C groups and this superiority was maintained throughout all the tests for both boys and girls.

A reference to the preceding figures shows no exception to this general result. A further fact stands out in these graphs, namely that the superiority of F over C is much more marked for Sydney than for London.

A more detailed analysis of the results was undertaken to discover how this rather challenging phenomenon comes about. Each set of results, for boys and girls in London and Sydney, was divided into standard deciles and each decile for London was compared with its fellow for Sydney (Figs 4 and 5, overleaf).

The remarkable appearance is presented that not only are the means for the top deciles (Sydney and London) farther apart than those for the bottom deciles, but that a reasonably regular gradation is shown in the intermediate deciles.

The Figures all show similar converging lines, but the convergence is not equally distinct in all cases. A further examination was therefore made of the terminal deciles as an overall test of the tendency for convergence; the mean value was calculated for each terminal decile taken as a whole, and the results assembled in Table III (overleaf).

In the arm test the Sydney/London ratio is substantially higher in the top decile than in the bottom decile for both boys and girls, and the overall convergence is very marked. This convergence is also seen for both boys and girls in the leg test, where the superiority of the Sydney children is marked in the top decile but negative in the bottom decile.

FIG. 3.—Relative performances (girls).

FIG. 4.—Comparison of deciles of London and Sydney boys.

FIG. 5.—Comparison of deciles of London and Sydney girls.

TABLE III
MEAN VALUES IN FOOT POUNDS FOR DECILES LISTED

Test	Sex	Decile	Arm				Leg			
			Boys		Girls		Boys		Girls	
			Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
London	..	..	638	309	576	279	1,197	483	963	391
Sydney	..	..	886	356	699	296	1,531	465	1,072	364
Ratio: Sydney/London			1.39	1.15	1.21	1.06	1.28	0.96	1.11	0.93

ANALYSIS OF THE RELATION OF PERFORMANCE
TO BODY-WEIGHT

Previous experience has shown that in a variety of athletic performances the absolute result is frequently a linear function of body-weight over a fairly wide range, *e.g.* in a cycling race the competitors may range in weight from about 120 to nearly 180 lb., yet neither the lighter nor the heavier men have much advantage in hill climbing, where clearly the major work consists in lifting the body-weight. The lighter cyclist has a lighter cycle and this helps to maintain

equality. Moreover, in an extensive experience of laboratory tests over hundreds of cases, in which each subject worked on the bicycle ergometer against a standard fraction of his body-weight as load, it was found that neither the lighter nor the heavier men were favoured.

For this reason it was considered that in the limited weight range in question it would be worth while to calculate the constants for each group to determine the regression line of performance on weight. This was done for both boys and girls.

The graph for boys is shown in Fig. 6; that for girls is similar in shape but the differences in slope are less marked. A statistical investigation of the reality of the difference in the regression lines, considering boys as one group and girls as another, shows that the difference is real at the probability level 0.000001. This means that it is about a million to one in favour of the reality of the difference.

Fig. 6.—Boys' work capacity in relation to body-weight in London and Sydney.

Since each pair of graphs shows a point of intersection, the principle mentioned above that performance (P) is apt to be a linear function of weight (W) was applied by calculating the ratio P/W at this point. It was then calculated whether this ratio was maintained at the higher weight levels (Table IV).

TABLE IV
RELATION OF PERFORMANCE TO WEIGHT
 P/W IN ARBITRARY UNITS

Sex	Boys		Girls		Boys + Girls	
Weight Group	Lighter at 24 lb.	Heavier at 40 lb.	Lighter at 24 lb.	Heavier at 40 lb.	Lighter at 24 lb.	Heavier at 40 lb.
London	66	56	64	61	65	58+
Sydney	66	71	64	65	65	68

The following facts are demonstrated by Table IV:

- (1) There is little difference between the work capacity of the small boys and the small girls in relation to their weight in either London or Sydney.
- (2) As weight increases in the London children there is a decided falling off of work capacity in relation to body-weight, the difference being more marked in the boys than in the girls.
- (3) As weight increases in the Sydney children there is no falling off of work capacity in relation to body-weight but rather a slight increase; this increase is quite marked in the boys but not significant in the girls.

In commenting on the terminal deciles above, it was pointed out that the relative performances—London/Sydney—were not very different in the lowest decile, but that Sydney showed marked superiority in the top decile. It may be asked whether this phenomenon has any relation to the trend of the P/W ratio with increase of body-weight—the ratio being much the same in both cities in smaller children, but markedly superior in Sydney in larger children.

The underlying common factor may well be that most of the lighter children come from the C groups and most of the heavier ones from the F groups; it has already been shown that F Sydney scores well above F London.

The question naturally arises whether the difference in the food position in the two countries is in any way concerned. The writer was very struck by the remarkable organization obtaining throughout the London schools whereby hot midday meals are made available for the children, together with regular supplies of milk.

If the apparent superiority in some respects of the C London over the C Sydney children is real, it may be related to the question of food, since in Sydney there is no such provision for meals although the milk position is much the same. Food neglect in children may have been remedied in London to a better degree than in Sydney.

The falling off of performance in the heavier London children may be due to the fact that bigger children require more food, and it may be worth inquiring whether this additional requirement is generally available to these bigger children.

The writer well recalls that, when he was present at the Helsinki Olympic Games in 1952 as Scientific Adviser to the Australian team, there were many discussions on food among the athletes from various countries. He gained the impression that the British athletes as a group were convinced that they were handicapped in comparison with those from other countries (especially America and Australia), in that they appeared to be typically "protein hungry" because, as they claimed, of the limited availability of meat in Britain.

Another fact to remember is that the children tested in London were born during the war years. This could hardly account for all the phenomena discussed above, but might have some undetermined bearing on the general result.

Another factor which merits consideration is a possible difference in motivation between the two groups of children. It has been suggested that "Australians are deviating toward the American way of life in which desire to be best in everything

motivates both children and adults". There may be some truth in this idea, though I cannot recall any facts in my experience which would support it for adult athletes—let alone children. I must confess that to begin with I wondered whether an Australian experimenter could gain the confidence of the English children as easily as that of Australian children, and whether he would be able to inspire the former to try their hardest. From the first English group onwards, however, my fears were dispelled, and I was deeply impressed by the children's determination, real eagerness to excel being the keynote of their attitude. The detailed analysis of the relation of performance to body-weight, which is the basis of the main differences between the London and Sydney groups, leaves little scope for any appreciable difference in motivation.

SUMMARY

(1) A new type of ergometer is described which automatically readjusts any tendency to variation in load so that the load is maintained constant throughout the experiment.

(2) The ergometer is simple of construction and easily transported, and can be readily used for laboratory tests on groups of subjects in widely different places.

(3) A comparative study was undertaken to apply tests for work capacity to different classes of children in London and corresponding groups in Sydney.

(4) In both cities sample schools were selected to compare children living in the more congested areas (C) with those living under more favourable conditions (F). The study was limited to 10-year-old children in order to secure sufficient numbers for comparison. In each city the number tested exceeded three hundred.

(5) The work capacity of the major muscle groups below the waist and of similar groups above the waist was tested.

(6) An investigation was made of factors in a child's experience which might influence individual results; it was established that such differences are relatively small and did not influence the London/Sydney comparisons.

(7) Little difference was found in the heights and weights of the 10-year-old children in comparable schools in the two cities.

(8) In both cities the heights and weights of the F children were substantially above those of the C

children, and the F groups accomplished much more work than the C groups.

(9) When the results of the two tests are combined for all round comparison the F Sydney groups were found to be well ahead of the F London groups. In the boys this superiority was over 20 per cent. and in the girls about 13 per cent. All the C Sydney groups appeared a little superior to the C London groups, but this difference was too small to be significant.

(10) Analysis of the extreme deciles in the four groups, London and Sydney, boys and girls, showed a clear superiority of Sydney above London for the top decile in each, but little difference if any in the bottom deciles. In the leg test, bottom decile, Sydney appeared slightly inferior to London, but the difference was not statistically significant.

(11) When the results for the two cities were compared by considering the ratio of performance to body-weight it was found that the lighter children, both boys and girls, in Sydney were no better than, and possibly inferior to, those in London. As the weight of the child increased, however, the superiority of the Sydney groups over the London groups became more marked.

The facts established in (10) and (11) above pose a problem. Why should the heavier children in Sydney—both boys and girls—work at higher rates in the tests than their counterparts in London, while the lighter ones do not? One explanation could be that the ratio of muscle to fat is greater in the heavier Sydney groups than in the heavier London groups. It may be asked whether the fact that protein food is more freely available in Sydney than in London has any bearing on the finding.

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APPENDIX A

The principle of the new ergometer (Fig. 7) depends on dividing the friction band into two parts, that connected to the lighter weight (freely suspended at rest) having a greater coefficient of friction (C.F.) than that connected to the heavier weight.

FIG. 7.—Principle of action of the new ergometer.

W. Relatively large weight compared with a smaller w .

H.F. That part of the friction band with a higher coefficient of friction

L.F. That part of the friction band with a lower coefficient.

(A) At rest (W resting on floor).

(B) Wheel revolving in direction indicated by arrow.

When the wheel is rotated (provided that the ratio W/w lies within a certain range) sufficient friction is available to lift W . As this is lifted the total friction operating on the rim of the wheel steadily decreases until it reaches the value $(W - w)$ when the system comes to equilibrium. If any subsequent variation of total friction occurs, the band automatically moves in a direction to compensate for it; if the friction increases the band moves so as to reduce friction and *vice versa*. An automatic self-adjusting system is thus obtained and any pre-arranged load which may be set to begin with will be maintained at at constant value. In general a suitable weight carrier is attached to each end of the band, the weights of the empty carriers being such that in motion the junction point of the two portions of the band moves about 45° on the wheel. This gives a convenient position of equilibrium, so that any subsequent migration of this junction point sets in motion substantial adjusting forces. Any predetermined degree of friction or total load may be increased by placing a heavier weight in the larger carrier and a lighter one in the smaller carrier,

keeping the ratio of the added weights the same as the ratio of the weights of the carriers.

Preliminary tests showed that the device worked well, but it was not easy to make any given system of band plus weights cover a wide range of resistances.

It was difficult to find materials suitable for such a double band with sufficiently different Cs.F., for after continual use the band with the higher C.F. became smoother so that the C.F. decreased and might not suffice to raise the larger weight from the floor.

A given composite band gave satisfactory service for several months' work involving tens of thousands of revolutions, but finally developed irregularities and had to be discarded.

Various changes were made in the system during a period of nearly 4 years. The pairs of materials tried for the double band are set out below:

COEFFICIENT OF FRICTION	
Higher	Lower
Cotton webbing	Thin flexible wire in groove on rim
Rubber	Cotton webbing
Rubber	Steel band
Cork-faced cotton band	Steel band
Leather	Cotton webbing
Leather	Steel band
Brake lining (asbestos)	Cotton webbing
Brake lining (asbestos)	Steel band

As it would appear advisable, at first sight, to secure a high ratio between the Cs.F. of the two parts of the band, the combination of rubber and steel gave better results than other combinations, since this gives a ratio of 6 or 7 to one, while most of the other combinations give ratios of about 3 or 4 to one. Two difficulties arose, however, when such a band had been in use for several months:

(a) When the machine had been left unused for 10 days or so, the rubber seemed to "stick" so that it started up with a jerk, and the band flew off.

(b) Such a high ratio is apt to produce abrupt changes in resistance with relatively minor changes of position and this may lead to troublesome oscillation.

The combination of cork-faced fabric and steel also yields a high ratio (about 6 to 1) but the cork has behaved much more constantly than the rubber and the two ergometers have been running with this combination for years without breakdown.

Another difficulty sometimes arises in that the system does not continue to balance indefinitely

with increase in the absolute values of W and w even though the ratio of W and w is kept constant. Thus the system may balance well with weights of say 8 and 2 lb. with a W/w ratio of 4, and yet with heavier weights of 16 and 4 lb. with the same ratio the large weight may not be lifted from the floor when the wheel starts revolving, or after being lifted may sink slowly back again. Adjustment may quickly be made by adding equal weights to the carriers on each side, so that while $W - w$ is kept the same, the ratio W/w is slightly reduced and W is lifted into free equilibrium again.

A further improvement was made by using steel for the band with the lower C.F. and canvas for the band with the higher C.F. A small pot of oil was arranged with a wick to touch the rim of the wheel and provide a film of oil. The effect was to decrease the friction of the metal with little or no decrease in the friction of the canvas. In some cases it would appear that the friction of the canvas was even slightly increased. The difference between the two coefficients of friction was thus widened to the fullest extent. This device has been in continual use for about 4 years.

APPENDIX B

It was thought advisable to make some general comparisons combining the results of the separate tests for arms and legs (Figs. 2c, 3c, 4c, 5c).

Equal weight was given to each test by the following procedure:

(1) All the corresponding results for London and Sydney were pooled, and the mean values were calculated. This yielded four mean values:

boys' arms boys' legs girls' arms girls' legs.

(2) If the absolute performance of a given child for the

leg test be L_x , and the mean for London plus Sydney L_m , the relative performance was calculated as $\frac{1000 L_x}{L_m}$, the arbitrary factor 1000 being used to clear decimals.

The same child's arm test was also calculated as a relative performance by using the expression $\frac{1000 A_x}{A_m}$.

These expressions enabled his combined performance (arms plus legs) to be assessed as $\frac{1000 L_x}{L_m} + \frac{1000 A_x}{A_m}$.