SOME NOTES ON PHYSIQUE AND ATHLETIC TRAINING

WITH SPECIAL REFERENCE TO HEART SIZE

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In the course of the last two years two groups of athletes—the Oxford University Women's Boat Club and the Oxford University Athletic Club—have been studied. In each case the aim was to discover whether the physique of these undergraduates differed from that of the undergraduate population as a whole. The O.U.W.B.C. represents a group of women students who elected to take part in exceptionally strenuous physical activity. The O.U.A.C. consists of men athletes highly selected in relation to either school or general university level. If it can be shown that fundamental differences exist between the physique of athletes and others, then further questions arise. Are these differences related to success or failure in the particular sport concerned and, if so, do they represent inborn ability or are they the result of training? Again, could these attributes, once identified, be used for the purpose of selection, or even to predict performance? Satisfying answers to such questions would help incidentally to counter popular opinion or prejudice expressed in such views as "athletics injure the heart," or in the case of a woman rowing, as one landlady picturesquely put it, that it "would turn her into a man."

The Oxford University Women's Boat Club

In the O.U.W.B.C. a medical examination is required by statute. This was undertaken for the present series on condition that members submitted to examination, including a chest radiograph before and after a period of nearly four weeks' heavy training in preparation for the race against Cambridge. Crews were required to row on an average four miles daily, and after watching them from the towpath no doubt was left that they worked hard. Chest radiographs (P.A.) were taken under standard conditions at 6 feet with the subject sitting.

Comparison in Physique with Other Women Undergraduates

This is illustrated in Table I, in which the measurements of rowers are compared with those of other women undergraduates. Only in the case of chest depth and of the body ratio biacromial/bi-iliac was the difference significant, and even here the observed differences in means divided by their standard errors were only 2.1 and 2.2 respectively. Although just reaching the 5% level of statistical significance, the difference is of such small degree that it would require a larger sample than 18 to show it convincingly. In addition the means for those in the University boat were the same as for all rowers. In height, weight, sitting height, and leg length, in the other measurements and body proportions derived from them, there was no significant difference between this group of rowers and non-rowers. Nor was there any significant difference in measurements made on the cardiovascular system.

TABLE I.—Measurements of Rowing Women Compared With Those of Others

Measurement	O.U.W.B.C.		Other Women Undergraduates		
	No.	Mean	No.	Mean	S.E.
Height (in.)	18	65.4	178	65.1	±0.18
Weight (lb.)	18	132.9	178	133.8	±1.25
Sitting height (in.)	18	35.0	131	35.0	±0.13
Leg length (subischial) (in.)	18	30.0	131	30.1	±0.15
Biacromial (cm.)	18	36.0	132	35.8	±0.14
Chest width (cm.)	18	25.6	132	25.8	±0.11
Chest depth (cm.)	18	17.9	132	18.7	±0.13
Bi-iliac (cm.)	18	27.7	131	27.8	±0.10
Body proportions:					
Ht./√Wt. (in./lb.)	18	12.8	132	12.8	±0.07
Biacromial × 100/bi-iliac	18	130.4	129	126.3	±0.64
Chest width × 100/chest depth	18	145.4	128	141.0	±1.24
Sitting ht. × 100/subischial	18	115.5	130	116.2	±0.55
Cardiovascular:					
B.P. systolic (mm. Hg)	18	126	178	125	±1.03
B.P. diastolic (mm. Hg)	18	79	178	83	±0.74
Resting pulse (lying, per min.)	18	75	178	75	±1.12
Heart transverse diameter (in cm. before training)	13	11.9	219	11.5	±0.07

Effect of Four Weeks' Strenuous Training on Heart Size

To assess the size of the heart by its transverse diameter* and more particularly the changes that might occur in the transverse diameter of the heart of rowing women during training, it was considered best to compare the hearts of rowing women with a control group of non-rowers who had been x-rayed more than once under the same standard radiographic conditions (see Table II). In each case the mean transverse diameter for the group was slightly reduced in the second picture. Because a reduction in the mean transverse diameter was present in both groups it might be argued that some alteration in technique had occurred.

The 5% level of significance cannot carry conviction, however, with such small samples as 13, and a subsequent check with a larger sample of controls did not confirm significant reduction at the second radiograph. Again, even if an alteration in technique was present and a mean gain of 0.18 cm. had occurred among rowers—that is, 0.44–0.26 cm.—such a difference would not be significant. There is no evidence to support a suggestion of any general change occurring in the transverse diameter of heart shadows as a result of nearly four weeks' strenuous training. The maximum individual increase observed in rowers was 0.85 cm., in non-rowers 0.50 cm.; the maximum individual decrease was 1.45 cm. in rowers, 1.80 cm. in non-rowers. Incidentally the findings illustrate the danger of assessing change in heart size from two teleradiographs alone, because an apparent change of up to ± 1.5 cm. in the transverse diameter of any one heart occurred even under standard conditions with careful radiography.

Before leaving the question of the effect of training, there is one other more general matter to note. Towards the end of term several members of the first eight were showing signs of physical tiredness, in

*Bedford and Treadgold (1931) discussed the size of the healthy heart and its measurement. They considered the most reliable index of heart size to be its total transverse diameter, and the orthodiagram the quickest and most accurate method of assessing it. With a 2-metre teleradiograph they considered a reduction of 5 to 10% in linear measurement necessary to obtain actual heart size. They stressed the difference associated with respiration, height, weight, body build, and posture, stating that the transverse heart diameter may be reduced 0.2 cm. by change of posture from lying to sitting, and again from sitting to standing. With exposures of 0.1 second the teleradiograph exposure may coincide with ventricular systole and thus cause reduction of the transverse diameter.

TABLE II.—*Teleradiographic Transverse Diameter of the Heart Before and After Training*

Group	No.	Mean Transverse Diameter of Heart		Mean Diff. in Diam. (cm.)	S.D. of Diff. (cm.)	S.E. of Diff. (cm.)	Obs. Diff. S.E. Diff.
		1st X-ray (cm.)	2nd X-ray (cm.)				
Rowers in training ..	13	11.95	11.69	-0.26	0.61	0.17	1.53
Control non-rowers ..	13	12.71	12.27	-0.44	0.79	0.22	2.0

particular pallor and certain rather less well defined signs in behaviour and expression. The individuals who showed these signs were those who worked in the morning, rowed in the afternoon, and took part in some other university activity—for example, the opera or other club—in the evening. The effect was therefore to be attributed more to a temperament inclined to do too much rather than to one particular activity such as rowing. It affords confirmation for the customary advice of rowing coaches to go to bed early. Another and more lively impression was the keen enjoyment which members of the club obtained from their rowing. Few doctors would wish to deprive them of this enjoyment except for firmly established medical reasons.

Oxford University Athletic Club (Men)

It is common observation that few athletes, if any, reach the top class both as sprinters and as long-distance runners. It seemed worth while to inquire whether this difference is linked with demonstrable anatomical variation. Although athletes have for cen-

turies attracted the interest of physicians and physiologists and a slow pulse has long been recognized as a special feature, no constant or precise combination of characteristics has been identified which appears to endow one individual above fellow competitors, a combination of characteristics such as might lead to selection and successful prediction of performance. Cureton (1947) has discussed "all-out" athletic performance in interesting detail, referring especially to comparisons between the heart x-ray shadows of Olympic competitors and normal individuals, and to the anthropometric measurements made by Kohlrausch (1929) on more than 300 Olympic athletes.

One of the most interesting accounts, however, is given by Bramwell and Ellis (1931), who reported on 28 marathon runners. Compared with other Olympic athletes these were found to be older men, in the late twenties or early thirties, men of lighter build, with lower resting pulse, and rather higher systolic blood pressure. Their most striking feature, however, was that they possessed hearts relatively much bigger than those of other athletes. The investigators' interest centred on the heart, and, although the lighter build of marathon runners was mentioned, no record of height was published with which weight could be related in any precise measure of build. No distinctive characteristic was found to separate sprinters from middle- and long-distance runners. Nor was there any constant physical finding which differentiated successful marathon runners from less successful competitors.

The material now to be examined comes from a combined clinical and photogrammetric study of the O.U.A.C. (1949) undertaken by Dr. J. M. Tanner in

TABLE III.—*Physical Measurements of Athletes Compared by Athletic Events*

	Sprinters. 100, 220, 440 yds.					Long Distance. 880 yds. and Over					Jumpers. High Jump, Hurdles, Long Jump, Pole Vault				
	No.	Mean	Min.	Max.	Range	No.	Mean	Min.	Max.	Range	No.	Mean	Min.	Max.	Range
1. Height, cm. ..	16	178-0	168-6	183-0	14-4	10	179-1	173-5	183-5	10-0	17	180-7	168-6	194-6	26-0
" in.		70-1	66-4	72-1	5-7		70-5	68-3	72-3	4-0		71-1	66-4	76-6	10-2
2. Weight, kg.	16	71-0	60-8	78-0	17-2	10	68-8	63-6	77-2	13-6	17	73-3	60-8	87-2	26-3
" lb.		156-3	134-0	172-0	38-0		151-5	140-0	170-0	30-0		161-5	134-0	192-0	58-0
3. Sitting height, cm. ..	16	92-7	89-9	96-1	6-2	10	92-7	89-4	94-9	5-5	17	93-7	88-4	98-6	10-2
" " in.		36-5	35-4	37-8	2-4		36-5	35-2	37-4	2-2		36-9	34-8	38-8	4-0
4. Leg length, cm. ..	16	85-3	78-6	90-0	11-4	10	86-5	83-2	91-6	8-4	17	87-1	80-2	99-0	18-8
" " in.		33-6	30-9	35-4	4-5		34-1	32-7	36-1	3-4		34-3	31-6	39-0	7-4
5. Ratio 3/4 ..	16	1-09	1-01	1-16	0-15	10	1-07	1-00	1-14	0-14	17	1-08	0-97	1-18	0-21
6. Ht./ $\sqrt[3]{\text{Wt.}}$ (cm.-kg.) ..	16	43-0	40-6	45-6	5-0	10	43-6	42-4	44-9	2-5	17	43-3	41-0	46-3	5-3
" " (in.-lb.) ..		13-0	12-3	13-8	1-5		13-2	12-8	13-6	0-8		13-1	12-4	14-0	1-6
7. Tr. diam. heart, cm. ..	16	13-0	10-9	16-3	5-4	7	14-2	12-4	16-3	3-9	17	13-3	11-5	14-9	3-4

	Heavy Events. Javelin, Discus, Shot					Control. Two Colleges				
	No.	Mean	Min.	Max.	Range	No.	Mean	Min.	Max.	Range
1. Height, cm. ..	6	183.5	175.9	197.0	21.1	297	177.5	157.0	203.0	46.0
" in. ..		72.3	69.3	77.5	8.2		69.9	61.8	79.9	18.1
2. Weight, kg. ..	6	83.7	67.6	95.0	27.4	297	68.4	47.7	104.0	56.3
" lb. ..		184.3	149.0	209.0	60.0		150.6	105.0	230.0	125.0
3. Sitting height, cm. ..	6	95.8	93.3	100.5	7.2	241	93.1	87.0	102.0	15.0
" " in. ..		37.7	36.7	39.6	2.9		36.7	34.3	40.2	5.9
4. Leg length, cm. ..	6	87.7	82.6	96.5	13.9	241	83.7	72.0	94.0	22.0
" " in. ..		34.5	32.5	38.0	5.5		33.0	28.4	37.0	8.6
5. Ratio 3/4 ..	6	1.09	1.06	1.13	0.07	237	1.11	1.02	1.27	0.25
6. Ht./ $\sqrt[3]{\text{Wt.}}$ (cm.-kg.) ..	6	42.4	41.3	44.2	2.9	359	43.6	37.0	47.6	10.6
" (in.-lb.) ..		12.8	12.5	13.4	0.9		13.2	11.2	14.4	3.2
7. Tr. diam. heart cm. ..	6	14.0	12.8	14.8	2.0	393	12.8	9.9	16.3	6.4

conjunction with me. Dr. Tanner took various anthropometric measurements, and he has very kindly given me permission to use his records of the height, weight, and sitting height of these athletes. Subischial leg length is derived by deducting sitting height from total stature. Two body proportions have been calculated: height/cube root of weight, and the ratio of sitting height to leg length.

Table III gives a summary of the measurements. The samples are too small for any fine degree of statistical treatment between the various types of field event. Nevertheless, calculation of the means and range is interesting in several ways.

Leg Length.—The longest pair of legs was found in a high jumper. He and a discus thrower had longer legs than any in a control group consisting of 241 men from two colleges. The average length of leg was shortest in the controls, slightly greater in sprinters, greater still in long-distance runners, high jumpers, and hurdlers, and greatest in the small group competing with discus, javelin, and shot. The ratio of sitting height to subischial leg length also reflects the longer legs of athletes. No athlete had a body longer in relation to the length of his legs than is reflected in the ratio index 1.18, yet indices up to 1.27 were found among controls, and 27% of controls had ratio indices above 1.14, which was the maximum for a long-distance runner.

Height.—With regard to mean height, all groups of athletes, whether sprinters, long-distance runners, jumpers, or others, were taller than the controls. Of the athletes, the javelin, discus, and shot group were tallest, and sprinters the shortest. Relatively short men (66 in.) may sprint 100 yards in 10.2 seconds or clear 9 ft. 9 in. in the pole vault. The smallest range of height was found in 10 middle- and long-distance runners (880 yards and over), who were 70.5 ± 2 in. tall.

Weight.—With regard to mean weight, middle- and long-distance runners were the lightest athletes, though not lighter than the control group, and their range of weight (30 lb.) was also the smallest. All types of athletes had mean weights above that of the controls, which was 150.6 lb. Sprinters were 5.7 lb. above, jumpers 10.9 lb., and those in heavy events 33.7 lb.

Height/ $\sqrt[3]{\text{Weight}}$.—The ratio $\text{Ht.}/\sqrt[3]{\text{Wt.}}$ is a measure of linearity of body build. A thin man, for example, has a high ratio; the average is 13.2, and those of stocky or tubby build have lower ratios. As might have been expected, men in heavy events had the lowest mean, and also a small range. The highest mean was in long-distance runners, with an average build equal to the control series. Sprinters as a whole (if the 100, 220, and 440 yards are included) are not easily distinguished from long-distance runners in either height, weight, or the ratio $\text{Ht.}/\sqrt[3]{\text{Wt.}}$; but it is interesting to note that the lower body-build ratios were found in sprinters, stockier men, whose competitive distance did not exceed 100 yards. In four such men the ratios were 12.3, 12.8, 12.9, and 13.0, whereas in five quarter-milers the ratios were 12.9, 13.0, 13.1, 13.3, and 13.4.

Heart Size.—Heart size may influence efficiency in running long distances, and reference has already been made to Bramwell and Ellis's findings in marathon runners. In considering the transverse diameter of the heart by tele-radiograph there was a range in the present series of 10.9 to 14.8 cm. among 100- and 220-yard sprinters, and 13.4

to 16.3 cm. among quarter-milers and long-distance runners. Perhaps the first point of interest is that a wide range of heart size, from 10.9 to 16.3 cm. transverse diameter, appears to be consistent with high athletic achievement. This is almost comparable to the full range of the control series (see Table IV). The next point is that there is an overlap of 1.4 cm. between sprinters (100 and 220 yards) and longer-distance runners.

Selective Characteristics

Now it may be argued that a combination of long legs, minimum weight with adequate musculature, and a large healthy heart should produce a runner with the best potential for long distances. The data for testing this notion are assembled in Table V, in which the values for each dimension are multiplied together.

TABLE V.—Selective Characteristics in Middle- and Long-Distance Runners Compared with Sprinters and a Control Series

Ref. No.	Best Events (Yards)	Trans. Diam. Heart (cm.) (1)	Ratio $\text{Ht.}/\sqrt[3]{\text{Wt.}}$ (2)	Leg Length (cm.) (3)	Product 1×2	Product $1 \times 2 \times 3$
<i>Middle- and Long-distance Runners (7)</i>						
6	880-5,280	15.3	13.5	91.6	206	18,869
12	440-880	16.3	12.9	85.4	210	17,934
4	220-880	14.0	13.0	90.0	182	16,380
10	880-1,760	13.9	13.2	86.0	184	15,824
13	880-5,280	14.5	12.8	84.1	185	15,558
26	880	13.4	13.3	87.4	178	15,557
27	1,760-5,280	13.7	13.5	84.0	185	15,540
Mean values		14.4	13.2	86.9	190	16,523
<i>Sprinters (11) (excluding 440 yards)</i>						
21	100-220	12.8	13.4	90.0	172	15,480
16	100	14.8	12.3	84.5	182	15,379
15	100	13.2	13.0	88.2	172	15,170
20	100-220	13.4	13.0	85.9	174	14,946
23	100-220	12.6	13.3	85.8	168	14,414
34	100-220	12.7	12.9	87.2	164	14,301
28	100	13.3	12.9	80.8	172	13,897
31	100-220	11.8	13.8	83.9	163	13,676
19	100-220	12.8	12.7	83.0	163	13,529
29	100	11.7	12.8	83.4	150	12,510
9	100-220	10.9	12.3	78.6	132	10,375
Mean values		12.7	13.0	84.7	165	13,971
<i>Control Series (359 men)</i>						
Mean values No. in sample		12.8 (393)	13.2 (359)	83.8 (241)	169	14,180

It will be seen from this table that a value of 175 for heart size multiplied by height/ $\sqrt[3]{\text{weight}}$ ratio would serve to distinguish most of the sprinters from long-distance runners. Only one sprinter (No. 16) had a product above 175, but he had a height/ $\sqrt[3]{\text{weight}}$ ratio of 12.3, representing a body build which may be so heavy that it cannot compete at more than 100 yards without incurring an excessive handicap through progressive oxygen debt. There is, it seems, something in the notion that a combination of heart size and physique may influence choice of particular athletic events.

To test this idea further, including length of leg as a possible factor, the product of heart size, height/ $\sqrt[3]{\text{weight}}$

TABLE IV.—Percentage Distribution of Transverse Diameter of the Heart

		Transverse Diameter of Heart in cm.														Mean (cm.)	S.E.	S.D.
		9.0-9.4	9.5-9.9	10.0-10.4	10.5-10.9	11.0-11.4	11.5-11.9	12.0-12.4	12.5-12.9	13.0-13.4	13.5-13.9	14.0-14.4	14.5-14.9	15.0-15.4	15.5-15.9	16.0-16.4		
393 men (%)	..	—	0.3	1.8	3.1	8.9	10.4	18.1	15.3	17.8	8.4	0.9	0.5	2.8	—	—	12.78	0.06
219 women (%)	..	0.9	2.3	5.9	16.4	15.5	22.8	12.8	13.7	6.4	1.8	—	—	—	—	—	11.5	0.07

ratio, and subischial leg length was calculated (see the last column of Table V). When this was done two things happened. No. 16 (a sprinter) came within the product range of sprinters, and No. 6 took the lead with the highest product among long-distance runners. He has since earned international fame as a most consistent and brilliant miler. The separation of long-distance runners from the sprinters in the series became complete at a level of 15,000. The evidence for the original hypothesis is therefore strengthened, but cannot be accepted as conclusive owing to the smallness of samples. Competitors in other events, such as hurdles and the quarter-mile, had values scattered within the total range of both sprinters and long-distance men.

It should be emphasized that the product levels found to discriminate between sprinters and long-distance runners should not be used for prediction. Nor should they, even if confirmation be obtained later of the selective influence described, be used in the present form. This is because, although certain allowance is made for the shape of an individual, none is made for his actual size: weight, for example, is well known as a factor to which heart size is directly related.

Comparison of Sprinters and Long-distance Runners

In comparing sprinters with the controls, it has already been noted that the sprinters (especially those competing at 100 yards only) were distinguished by a physique heavier and by being more muscular than the average. Heart size and leg length were, however, close to the general average, and both the products calculated were distributed equally above and below the general mean.

Long-distance runners, on the other hand, had hearts larger on the average than the controls, especially so where the $Ht./\sqrt[3]{Wt.}$ ratio indicated a stocky build—for example, ratios 12.8 and 12.9 occurred with diameters of 14.5 and 16.3 cm. There appears to be an optimum body build for long-distance running; the mean $Ht./\sqrt[3]{Wt.}$ ratio (13.2) was the same as in the control series, but the range (0.8) was the smallest of any group of athletes. A higher ratio than 13.6 may indicate that the weight of musculature is too slight for the task of long-distance racing. The legs of long-distance runners were longer than those of the controls. Lastly, the minimum products found (heart-size by body-build-ratio 178, and heart-size by body-build-ratio by leg length 15,540) were in each case far above the mean products for the control series, which were 169 and 14,180 respectively. There is evidence, then, to support a contention that the combination of these three items—heart size, $Ht./\sqrt[3]{Wt.}$, and leg length—is associated with a strong selective influence for successful long-distance running. Although it may still be maintained that heart size could be influenced by training over long periods, the view is less likely to be held that leg length, or for that matter the body-build ratio, is influenced in a material way by the differences in training of long- and short-distance runners. In any case heart size would seem to be of little consequence to sprinters.

The conclusion is reached that an individual's choice of athletic events may be recognized to be due, in greater degree than previously determined, to characteristics probably inborn. Training, it seems, does little to alter the basic physical type. If this is so, it is unlikely to bring about a change towards the optimum type which exists for certain events. Degree of success in any one

event may also depend on inherent characteristics to a greater extent than previously recognized. This concept in no way detracts from the importance of training to the individual who wishes to compete successfully.

Conclusions

Rowing Women

In comparing women who row and other women undergraduates, the body proportion biacromial-bi-iliac was slightly higher in rowers. On the other hand, chest depth was slightly greater among controls. In both cases the differences were significant, but only just reached the 5% level. No significant difference was found in the following measurements: height, weight, sitting height, leg length, biacromial, chest width, and bi-iliac; in the body ratios: $Ht./\sqrt[3]{Wt.}$, chest-width/chest-depth, or sitting-height/subischial-leg-length; and, lastly, the cardiovascular measurements of blood pressure, pulse rate, and transverse radiographic diameter of the heart.

No radiographic evidence of increase in the transverse diameter of the heart could be demonstrated in association with a period of strenuous training for an inter-university women's boat race.

University Athletes

Leg Length.—The average subischial leg length was shortest in the control group from two men's colleges, slightly longer in sprinters, greater still in long-distance runners, hurdlers, and high jumpers, and greatest in the small group competing with discus, javelin, and shot.

Body Build of Sprinters and Quarter-milers.—The body-build ratios of $Ht./\sqrt[3]{Wt.}$ for four sprinters whose competitive distance did not exceed 100 yards were 12.3, 12.8, 12.9, and 13.0, whereas for five quarter-milers the ratios were 12.9, 13.0, 13.1, 13.3, and 13.4. The sprinters as a group had a stockier type of physique.

Long-distance Runners.—(a) The product of the transverse radiographic diameter of the heart and the physical ratio $Ht./\sqrt[3]{Wt.}$ may serve to distinguish those with essential prerequisites in heart size and physique for successful long-distance running. (b) When the above product was multiplied by subischial leg length a still more complete separation of sprinters from long-distance runners was obtained. The highest product was found in a star performer. Both individual choice of athletic event and also to a certain extent the final level of success in athletics may be recognized to be due, in greater degree than previously determined, to what a man is born with rather than to the effect of his training. It remains to confirm the hypothesis presented by testing it against larger samples.

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