ON THE INFLUENCE OF EXERCISE ON THE GROWTH OF ORGANS IN THE ALBINO RAT

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For the past three years experiments have been carried on to determine the effect of long-continued exercise on the growth of organs in the albino rat. The main object of the present investigation was twofold: (1) to repeat the observations of Donaldson ('11) who found a slight increase (2.6 per cent) in the brain weight in albino rats which had been subjected to exercise for the period of six months, and (2) to extend the observations to other organs besides the central nervous system. The present paper includes the data obtained by the previous study, just mentioned, as well as the results of my own investigations.

TECHNIQUE

The opportunity for exercise was given by placing the test rats in a form of cage which was used by Slonaker ('08) in his studies on the daily activity of the albino rat. The revolving cage consists of a large cylindrical drum 58.5 inches in circumference, made of $\frac{3}{16}$ -inch wire mesh, which revolves on a stationary axle. On the axle was fastened the nest box and the food and water pans. The number of revolutions of the cage is registered by a cyclometer.

Albino rats one month old were placed in these cages for a period of three to six months, which is equivalent to seven to fourteen years of human life. Each cage contained a single rat. The rats used for the control were litter brothers and sisters of those in the revolving cages and were placed in the ordinary laboratory cages (one foot high, one foot wide and six feet long). The total number of rats examined was 36 controls

and 42 test animals. For the material of the 1914 series the present writer is under great obligation to Miss Caroline Holt, a graduate student at The Wistar Institute, who permitted the use of her exercised rats with their controls, and I wish to thank her for her courtesy in this matter.

METHOD OF COMPUTING THE AMOUNT OF ALTERATION

In determining the deviations of the organs in the exercised rats from those in the controls, the following method was used: As a first step, the weights of the various organs corresponding to the observed body length of the rats were computed by means of formulas (for various formulas see Hatai '13 and '14). This computation was made for both the controls and the exercised rats. The differences between the observed and computed values of both control and exercised are now transformed into percentages by taking the computed values as 100 per cent. Thus we obtain two sets of percentage values, one expressing the difference between the computed and observed values in the control rats, and the other expressing the difference between computed and observed values in the exercised rats. If exercise has not altered the organs of the animals at all, then these two sets of percentages should be alike within the limits of the normal fluctuations. If, on the other hand, exercise has altered the organs, these two sets of percentages should differ more or less according to the nature of the response to exercise. If in the case of any organ we now take the difference between the percentage value obtained for the controls and that for the exercised rats, this difference represents the amount by which the exercised rats, as compared with controls, depart from the value obtained by the formula. By the use of this procedure, successive series are thus referred to the formula values in each instance and since the deviations are measured by this means always from the same standard, they may be directly compared with one another.

In the case of the thymus gland, the age of the rats was taken as the basis for the computation, since the weight of the thymus is much more highly correlated with the age than with either the

weight or the length of the body (Hatai '14). The example taken from the 1911 male series (the second series in table 3), may serve to illustrate the method of comparison described above (table 1). Expressing in words the results as given in the last line of this table, these show that the exercised rats are 13.4 per cent heavier than the controls and have a tail 1.62 per cent longer.

AMOUNT OF EXERCISE TAKEN

The rats in the revolving cages often take a large amount of voluntary exercise. To illustrate this I have chosen an example from the 1912 series and given the average distance run during every 24 hours for the entire period of 93 days.

As will be seen from table 2, the distance run is almost incredible in some instances, the greatest average run for 93 days being 10 miles per 24 hours; a record made by one female. Since the rat is most active during the night (Slonaker '12) this daily run

TABLE 1

	BODY LENGTH (MM.)	TAIL LENGTH (MM.)	BODY WEIGHT (GMS.)
Controls: observed values	212	176	238.3
Controls: values calculated from formulas (body length taken as basis of computa- tion)		180	238.1
Percentage deviation of ob- served from calculated val- ues.....A		-2.22%	0.08%
Exercised: observed values	195	164	202.0
Exercised: values calculated from formulas (body length taken as basis of computation)		165	178.1
Percentage deviation of ob- served from calculated val- ues.....B		-0.60%	13.48%
Amounts by which the percent- ages for the exercised animals differ from those for the controls; i.e., B - A		1.62%	13.40%

TABLE 2

Showing the distance run by the exercised rats in a period of 93 days

EXERCISED RAT, NO.	NO. OF MILES PER 24 HOURS	SEX	EXERCISED RAT, NO.	NO. OF MILES PER 24 HOURS	SEX
8 B ₁₀	0.4	M.	7 A ₅	7.6	M.
7 A ₁₇	0.5	M.	7 A ₄	7.6	M.
8 B ₉	0.6	M.	7 B ² ₁₇	6.2	F.
7 B ² ₁₆	0.6	M.	7 B ₂₆	7.4	F.
7 B ₁₉	4.8	M.	6 B ² ₉₂	7.7	F.
7 B ₄₈	6.5	M.	6 B ² ₈₃	8.3	F.
6 B ² ₈₂	6.7	M.	8 B ₁₁	10.2	F.

was accomplished for the most part within a twelve-hour period. With the exception of the first four sluggish male rats, the average run was about $6\frac{1}{2}$ miles for males and 8 miles for females. Slonaker found that female rats were more active than the males and he further noticed considerable individual variation in the activities. The present results agree nicely with the observations of Slonaker. It is interesting to note also that the maximum average run by Slonaker's rats was 11 miles (average for one month) while that of mine was 10 miles per day for 93 days, thus showing a close agreement even in this respect. We do not know how active the wild Norway rats may be, but a considerable curtailment of the normal activity in the albino rats under domestication seems highly probable.

The effects of long-continued exercise on the body of the Albino as a whole, and on the organs, was the object of the present investigation.

INFLUENCE OF EXERCISE FOR 90 TO 180 DAYS ON THE EXTERNAL MEASUREMENTS AND ON THE ORGAN WEIGHTS

1. Alterations of the external measurements

The external measurements of the exercised albino rats contrasted with those of the controls are given in table 3.

To prevent misunderstanding or misinterpretation, a word of explanation touching the tables is in order. Using the series for 1911 males, the second one in table 3 (the same which has been used as an illustration for procedure on page 649), attention

is called to the following points: The entries for the control are the *observed* values—the entries for the exercised are the *observed* values. The percentages deviations of both controls and exer-

TABLE 3
Showing the external measurements in both control and exercised rats

	LENGTH (mm.) OF		WEIGHT OF BODY: GRAMS	DURATION OF EXERCISE: DAYS	AGE: DAYS	NO. OF RATS USED
	Body	Tail				
<i>Stock albino rat (Donaldson, '11) M. and F.</i>						
Control...	199	165.00	199.60	180	242	31
Exercised.....	195	163.00	192.80		242	24
Per cent: Exerc.-cont.		0.42	2.90			
<i>Stock albino rat, 1911 series M.</i>						
Control.....	212	176.00	238.30	180	215	21
Exercised.....	195	164.00	202.00		195	11
Per cent: Exerc.-cont.		1.62	13.40			
<i>Inbred albino rat, 1912 series M.</i>						
Control.....	212	184.00	217.30	180	212	9
Exercised.....	214	181.00	245.30		213	10
Per cent: Exerc.-cont.		-2.77	8.42			
<i>Inbred albino rat, 1912 series F.</i>						
Control...	191	174.00	155.40	180	215	6
Exercised.....	198	173.00	179.80		213	7
Per cent: Exerc.-cont.		-4.77	2.52			
<i>Stock albino rat, 1914 series M.</i>						
Control.....	176(F)	167.00	145.60	90	135	3
Exercised.....	198	178.00	220.90		135	4
Per cent: Exerc.-cont.		-2.56	11.35			
<i>Stock albino rat, 1914 series F.</i>						
Control.....	176	167.00	145.60	90	135	3
Exercised.....	182	171.00	159.40		135	4
Per cent: Exerc.-cont.		-1.60	-1.87			
Percentage by which exercised rats differ from controls. Same weight given to each series.....		-2.02	6.76			

cised from the formula values have been determined but *are not entered* in the table. The difference between these two percentage deviations is alone given in the table after ‘%: exerc.-contr.’ To test the correctness of these last figures it is always necessary to carry out the operations which have been described (p. 648). This same explanation applies to the other series in this table and also to the other tables 3, 4 and 5.

Body length. The average absolute length of the body is practically identical in both the exercised and control rats. The difference amounts to 0.5 per cent in favor of the controls. The data given by Donaldson ('11) for a single series show also a small difference of 2 per cent in favor of the control. We may conclude therefore that exercise does not alter the growth of body in length to any noticeable extent.

Tail length. The tail length with respect to body length tends to be slightly shorter in the exercised than in the non-exercised rats. The average difference is 2.02 per cent in favor of the control. The data given by Donaldson show practical identity in his series. However, the difference is noted in four out of my five series and I conclude therefore that exercise tends to retard the growth of the tail in length.

Body weight. A slight increase of 6.76 per cent is given in the average body weight for the exercised rats when compared with that of the non-exercised. This difference appears in four series out of five. Data given by Donaldson shows also an increase of 2.90 per cent in favor of the exercised. This relative gain in body weight of the exercised rats may be due in part to the absence of lung disease in the exercised rats. As will be seen later, most of the control rats were suffering from a lung infection, while most of the exercised rats were free from this. It is therefore possible that the increased body weights shown in table 3 are in some measure due to the slightly emaciated condition of the control rats, thus raising the relative value in favor of the exercised rats. I am therefore inclined to believe that in the case of the albino rat the body weight is not much affected by the form of exercise here given—though it may be slightly increased.

Considering these three external characters together, we may say that long-continued exercise does not modify significantly any of the characters here mentioned with the possible exception of the tail length, which shows a slight tendency to a deficit with respect to the body weight.

2. Alterations of the viscera

TABLE 4

Showing the weights of viscera of the exercised rats compared with those of the controls. Arrangement of data explained on p. 650.

	BODY LENGTH (mm.)	HEART	WEIGHTS (GMS.) OF				ALIM. TRACT	NO. OF RATS USED
			Kid- neys	Liver	Spleen	Lungs		
<i>Stock albino rat, 1911 series, M.</i>								
Control.....	212	0.886	1.768	10.21	0.611	1.796		21
Exercised..	195	0.904	1.867	10.35	0.589	1.588		11
Per cent: Exerc.-cont.		26.980	32.170	23.15	25.980	17.250		
<i>Inbred albino rat, 1912 series M.</i>								
Control...	212	0.784	1.627	8.50	0.445	2.325	7.86	9
Exercised.....	214	0.874	2.032	11.36	0.415	1.228	9.15	10
Per cent: Exerc.-cont.		7.380	17.300	22.46	-6.790	-82.990	9.49	
<i>Inbred albino rat, 1912 series F.</i>								
Control.....	191	0.587	1.246	6.48	0.395	2.205	6.77	6
Exercised.....	198	0.787	1.530	8.85	0.363	0.999	8.12	7
Per cent: Exerc.-cont.		17.430	8.310	17.24	-14.900	-89.970	7.52	
<i>Stock albino rat, 1914 series M.</i>								
Control.....	(F)176	0.595	1.054	6.19	0.651	1.000	8.27	3
Exercised.....	198	1.044	1.790	9.06	0.444	1.128	8.82	4
Per cent: Exerc.-cont.		37.680	25.280	13.12	-61.870	-15.160	-14.80	
<i>Stock albino rat, 1914 series F.</i>								
Control.....	176	0.595	1.054	6.19	0.651	1.000	8.27	3
Exercised.....	182	0.822	1.317	7.74	0.457	1.105	8.09	4
Per cent: Exerc.-cont.		27.130	11.930	12.72	-63.210	1.390	-9.76	
Average percentage by which exercised albino rats differ from controls. Same weight given to each series								
	23.320	19.000	17.74	-24.160	-33.090	-1.89		

From table 4 we note the following modifications.

Heart. In all the series the weight of the heart is considerably heavier in the exercised rats than in the controls. The average difference is 23.32 per cent in favor of the exercised rat.

Kidneys. The kidneys of the exercised rats are also heavier than those of the controls in all the series. We note the average difference of 19 per cent in favor of the exercised.

Liver. The weight of the liver is also heavier in the exercised rat in all the series. The difference is 17.74 per cent in favor of the exercised rat.

Spleen. On the other hand, the weight of the spleen is greater in the control than in the exercised. The difference amounts to as much as 24.16 per cent in favor of the controls. This difference does not appear to be due to a greater variability of the spleen, since it occurs in four series out of five, and furthermore, the same phenomena occurs in another series, which will be considered later (table 7). The reason why exercise retards the normal growth of the spleen with respect to body length is not clear.

Lungs. We notice the average difference of minus 33.90 per cent in the exercised lungs compared with the controls. In the case of the lungs, however, those heavier than normal for the body weight are associated with a lung infection. As a matter of fact, most of the control rats were infected, while the exercised rats were free from infection. It has already been noted that the infection of the lungs in the control rats was probably responsible in part for the relatively small body weight of the controls. It is highly interesting to see that exercise prevents, or at least delays, an onset of a very prevalent pulmonary infection in the albino rat.

Alimentary tract. The alimentary tract as here designated includes not only the digestive tract proper, such as the stomach, intestine, etc., but also all attached structures, as the pancreas, omentum, as well as fat deposited in them. As is shown in table 4, the alimentary tract is not evidently modified. We note an average difference of 1.89 per cent in favor of the controls. This small difference, associated as it is with the bal-

anced distribution of plus and minus variations, justifies our conclusion that exercise has not affected this part of the visceral system.

3. Alterations of ductless glands

Testes. The testes of the exercised rats show an average increase of 12.33 per cent when contrasted with those of the controls. This increase occurs in both the male series, thus showing the significance of the reaction.

Ovaries. The ovaries in the exercised rats show an increase of 84.33 per cent when contrasted with those of the controls. The difference between the exercised and controls in these organs is evident even at a glance. It is interesting to note that the sex glands of the Norway rats are normally heavier than those of the Albinos. The increase here shown as the result of exercise may possibly indicate a return to the wild form, not in size alone but also in fertility.

Hypophysis. The hypophysis responds to exercise differently according to sex. We note an increase of 10.25 per cent in the case of the male and a deficit of 22.23 per cent in the case of the female. The approach of the weights in the two sexes and the larger loss in the female bring about relations which I have observed in the wild Norway (Hatai '14 b).

Suprarenal glands. As in the case of the hypophysis, the suprarenal glands show also dissimilar reaction to exercise according to the sex. Thus we note practically no alteration in the male (0.84 per cent), while there is an increase of 47.76 per cent in the female—again relations such as the wild Norway shows (Hatai '14 b).

Thyroid. We note a difference of nearly 13.44 per cent in favor of the control rats.

Thymus gland. The thymus of the exercised rat shows a slight relative increase of 4.80 per cent when contrasted with that of the control. It occurs, however, in only two cases out of four, and furthermore the greater variability in the alteration suggests that the difference here noted may not be significant at all. We must await the results of future experiments to make any positive statement.

TABLE 5

Showing the weights of the ductless glands in the exercised rats compared with those in the controls. Arrangement of data explained on page 650.

	BODY LENGTH (mm.)	SEX GLANDS	WEIGHTS (GMS.) OF				NO. OF RATS USED
			Hypophysis	Suprarenals	Thyroid	Thymus	
<i>Stock albino rats, 1911 series M.</i>							
Control.....	212	2.2280					21
Exercised....	195	2.3380					11
Per cent: Exerc.-cont.		19.7800					
<i>Inbred albino rat, 1912 series M.</i>							
Control.....	212	2.3430	0.0085	0.0328	0.0344	0.0984	9
Exercised...	214	2.5030	0.0096	0.0339	0.0354	0.1085	10
Per cent: Exerc.-cont.		4.8800	10.2500	0.8400	0.2700	7.1800	
<i>Inbred albino rat, 1912 series F.</i>							
Control.....	191	0.0368	0.0113	0.0425	0.0273	0.1051	6
Exercised...	198	0.0602	0.0127	0.0622	0.0282	0.1698	7
Per cent: Exerc.-cont.		46.4200	-2.0200	27.3200	-5.4600	41.7000	
<i>Stock albino rat, 1914 series M.</i>							
Control.....	176 (F.)				0.0282	0.1931	3
Exercised...	198				0.0290	0.1355	4
Per cent: Exerc.-cont.					-25.8100	-25.4900	
<i>Stock albino rat, 1914 series F.</i>							
Control.....	176	0.0557	0.0076	0.0417	0.0282	0.1931	3
Exercised....	182	0.1145	0.0058	0.0656	0.0247	0.1836	4
Per cent: Exerc.-cont.		122.2500	-42.4300	47.7600	-22.7400	-4.2000	
Average percentage by which exercised albino rats differ from control. Same weight given to each series		12.33(M.) 84.33(F.)	10.25(M.) -22.23(F.)	0.84(M.) 47.76(F.)	-13.4400	4.8000	

From the above it is clear that most of the ductless glands are subject to a considerable alteration as the result of exercise. Beyond pointing out that the exercised rats show, in the case of the testes, ovaries, hypophysis and suprarenals, relations similar to those found in the wild Norway, I am unable to give an interpretation of the changes observed. The data are therefore presented without further comment except to repeat that the alterations here noted are constant and are not the result of a great inherent variability of these organs.

4. Alterations of central nervous system and of eyeballs

Brain weight. On the average the brain weight of the exercised rat is 4.02 per cent heavier than that of the controls. This relatively greater weight of the exercised rat is true not only on the average, but also for all the series given in table 6. A variation of 4 per cent is not usually regarded as a large figure, nevertheless it is certainly significant for this particular organ. Indeed, this gain of 4 per cent is the largest plus alteration so far obtained from our experiments. It seems safe to conclude from its constancy, as well as from relative uniformity of the value, that exercise increases the brain weight with respect to the body length. It should be noted also that the present results agree with the finding of Donaldson ('11) in this respect. It is not clear, however, whether this gain was due to a uniform enlargement of an entire mass, or to the increase of special divisions or structural components of the encephalon. A detailed analysis may settle this question in the future.

Spinal cord weight. The weight of the spinal cord evidently is not significantly altered. This is shown not only by its slight average modification of 0.88 per cent but also by the fact that the variation is not uniform in all the series. Donaldson found a difference of 0.65 per cent in favor of the control rat. All we can say about this part of the central nervous system is that exercise produces no significant alterations.

Amount of water in the brain and spinal cord. As shown in table 6, the percentage of water in the brain and spinal cord is

TABLE 6

Showing the weights of brain and spinal cord and of eyeballs of the exercised rats compared with those of the controls. Arrangement of data explained on p. 650.

	BODY LENGTH (mm.)	WEIGHTS (GMS.) OF		PERCENTAGE OF WATER		WEIGHT OF EYEBALLS (GMS.)	NO. OF RATS USED
		Brain	Sp. cord	Brain	Sp. cord		
<i>Stock albino rat (Donaldson '11) M. and F.</i>							
Control.....	199	1.920	0.597	78.41	71.45		31
Exercised.....	195	1.951	0.580	78.12	71.37		24
Per cent: Exerc.-cont.....		2.570	-0.650	-0.29	-0.08		
<i>Stock albino rat, 1911 series M.</i>							
Control.....	212	1.872	0.614	78.09	70.39		21
Exercised.....	195	1.866	0.564	78.08	71.05		11
Per cent: Exerc.-cont.....		3.670	3.000	-0.01	0.66		
<i>Inbred albino rat, 1912 series M.</i>							
Control.....	212	1.784	0.610	78.57	71.40	0.294	9
Exercised.....	214	1.868	0.603	78.40	71.20	0.299	10
Per cent: Exerc.-cont.....		3.940	-2.420	-0.17	-0.20	0	
<i>Inbred albino rat, 1912 series F</i>							
Control.....	191	1.715	0.547	78.24	70.89	0.288	6
Exercised.....	198	1.826	0.558	78.57	71.65	0.279	7
Per cent: Exerc.-cont.....		4.430	-3.220	0.33	0.76	-9.920	
<i>Stock albino rat, 1914 series M.</i>							
Control.....	176(F)	1.648				0.288	3
Exercised.....	198	1.836				0.288	4
Per cent: Exerc.-cont.....		5.990				-16.950	
<i>Stock albino rat, 1914 series F.</i>							
Control.....	176	1.648				0.288	3
Exercised.....	182	1.701				0.276	4
Per cent: Exerc.-cont.....		2.060				-10.910	
Percentage by which exercised albino rats differ from controls. Same weight given to each series.		4.020	-0.88	-0.02	0.41	-9.45	

not modified. This result agrees with the findings of Donaldson ('11).

Eyeballs. As a sample of the sense organs, the eyeballs were examined. As will be seen from table 6, the average weight of the eyeballs of the exercised rats is 9.45 per cent less than that of the non-exercised rat. The meaning of the smaller eyeballs in the exercised rats is not at all clear. I may mention, however, that from the data so far accumulated, the wild Norway rat has somewhat smaller eyeballs than the Albinos of the same body length.

THE EFFECT OF EXERCISE TAKEN FOR A PERIOD OF 30 DAYS

We have found that exercise taken for a period of 90 days produces changes in the organs to the same extent as exercise given for the period of 180 days (tables 3 to 6). It was thought interesting to determine the minimum period necessary to produce all the typical alterations. For this purpose the rats one month old were kept in the revolving cages for 30 days. The number of rats used was 6 controls and 6 experimented.

Without discussing the individual characters separately, we may make the following general statement.

(1) In no case are the alterations as large as those shown by the rats which had been kept in the revolving cages for the period of 90 or 180 days.

TABLE 7

Showing percentage values by which the several characters of the rats exercised for 30 days differ from those of the non-exercised. Males=3 controls and 4 exercised. Females=3 controls and 2 exercised. In this table only the final percentage values (i.e., for "% exerc.-contr.") are given.

	PER CENT		PER CENT		PER CENT
Tail length.....	0.4	Heart	8.0	Thyroid	2.0
Body weight.....	2.4	Kidneys	8.2	Thymus	-1.1
Brain.....	0.2	Liver	-9.5	Hypophysis { M.	25.7
Eyeballs.....	4.2	Spleen	-52.9	{ F.	10.6
Alimentary tract....	-7.7	Testes	9.2	Suprarenals { M.	8.0
Lungs.....	4.7	Ovaries	51.4	{ F.	30.1

(2) The amount of time necessary to produce the typical alterations varies according to different organs.

(3) While the heart and kidneys show a typical change, the liver shows a contrary modification. This may be due to a rapid utilization of reserve materials following a rapid growth, as well as the greater activity of the animal at this younger period.

(4) The early response of the sex glands to exercise may be the result of two combined factors; a greater supply of nutrition following the rapid circulation, and a strong tendency for growth of sex glands at this period of 50 to 60 days of age.

(5) Changes shown by other organs, particularly by the hypophysis, suprarenals and spleen, are very large. It is to be noted, however, that the weights of the hypophysis in the two sexes, despite the fact that both show a gain, tend to come together as in the 90 and 180 day series, while in the case of the suprarenals, the increase in the female is much the greater, a result again agreeing with the earlier series.

We may conclude from this short experiment that the effect of exercise is clearly shown in the rats which have been kept in the revolving cages for one month only, though the amount of modification varies considerably according to different organs.

TABLE 8

Showing the relation between heart weight and amount of exercise taken

DESIGNATION OF RAT	BODY LENGTH (mm.)	HEART WEIGHT (GMS.)	NO. OF MILES PER 24 HOURS	SEX
8 B ₁₀	222	0.725	0.4	M.
7 A ₄₇	212	0.771	0.5	M.
8 B ₉	215	0.799	0.6	M.
7 B ² ₁₆	218	0.853	0.6	M.
7 B ₁₉	201	0.720	4.8	M.
7 B ₄₃	220	0.888	6.5	M.
6 B ² ₈₂	217	1.149	6.7	M.
7 A ₅	205	0.907	7.6	M.
7 A ₄	212	0.915	7.6	M.
7 B ² ₁₇	198	0.745	6.2	F.
7 B ₂₀	191	0.724	7.4	F.
6 B ² ₉₂	205	0.838	7.7	F.
6 B ² ₈₃	201	0.891	8.3	F.
8 B ₁₁	197	0.762	10.2	F.

WEIGHT OF HEART IN RELATION TO THE AMOUNT OF
EXERCISE TAKEN

The variability in the activities of rats in the revolving cage suggested that there might exist a definite relation between the heart weight and the amount of exercise taken. To test this point table 8 was prepared. The data were taken from the 1912 series.

Among normal rats kept in the ordinary cages the correlation between heart weight and body length is very high (Hatai '13). Table 8 shows, however, that the correlation between the heart weight and body length in the exercised rats is almost zero, while, on the other hand, the correlation between the heart weight and amount of exercise taken is very high. To illustrate these points, I have divided the male records into three groups and the females into two groups according to the following plan:

<i>Male</i>	Group 1	Average for the first four sluggish rats
	Group 2	Average for the rats which ran 4.8 to 6.7 miles
	Group 3	Average for the rats which ran 7.6 miles
<i>Females</i>	Group 1	Average for the rats which ran 6.2 to 7.7 miles
	Group 2	Average for the rats which ran 8.3 to 10.2 miles

These average values are tabulated below.

		Body length (mm.)	Heart weight (gms.)	Mean distance run (miles)
<i>Males</i>	Group 1	217	0.787	0.5
	Group 2	213	0.919	6.0
	Group 3	209	0.911	7.6
<i>Females</i>	Group 1	198	0.769	7.1
	Group 2	199	0.827	9.3

From the above we notice that despite a greater body length in Group 1 (males) the corresponding heart weight is less in accordance with the least distance run. On the other hand, Group 3 (males) which has the least body length (209 mm.) gives almost as large a heart weight as Group 2, whose body length is 213 mm. In coincidence with this non-correlation

between the body length and heart weight, we notice a harmonious relation between the heart weight and amount of exercise taken.

In the female series we notice that despite the practical identity in their body length, Group 2, which had run the greater distance, surpasses in heart weight Group 1, which had run the lesser distance. These facts indicate clearly that the heart increased in weight in relation to the amount of exercise taken, as was anticipated.

GENERAL REMARKS

It is clear from the foregoing that long-continued exercise (equivalent to a period of 7 to 14 years in man) in the albino rat produces many striking alterations in the organs. The modifications here given are found to be true not only for all the series, but in most cases even for the contrasted pairs of rats, and thus the results are not dependent on the variability of these organs. I am confident that the alterations are the result of the long-continued exercise. It may not be out of place to mention here that a careful analysis of data has been made to see whether or not the infected lungs are in any way responsible for the changes observed in the organs. The results were negative.

The medical literature abounds with writings on the subject of 'exercise.' We find a universal recognition of hypertrophy of the heart following severe and long-continued exercise. I am not aware, however, that there are any similar statements concerning the modifications of other organs. Although from the results of physiological investigations on metabolism during or after severe physical exercise in man and in mammals, the occurrence of modifications in organs (such as the kidneys, liver, lungs, etc., besides the heart) are quite conceivable, yet we still lack the anatomical data for man.

From a purely biological standpoint, long-continued exercise has a special interest in the case of the domesticated albino rat. Former investigation has established the fact that the albino rat is a strain of the Norway rat (Hatai '07) and further, that these

two forms of the rat possess central nervous systems of a dissimilar weight, the Norway having an absolutely heavier brain and spinal cord for a given body weight (Donaldson and Hatai '11). Again, recently, I have shown that the relative weights of some of the ductless glands differ also in the Norway and albino rats (Hatai '14 b).

In rabbits, Darwin ('83) noted several physical differences, particularly in the cranial capacity between the wild and domesticated forms. The wild rabbits possessed a noticeably greater cranial capacity than the domesticated variety. More recently Lapicque and Girard ('07) have accumulated extensive data on the brain weights in wild and domesticated races. These two authors conclude also that the wild forms surpass the domesticated in their relative brain weights. Domestication, however, involves numerous interrelated factors which can be only slowly isolated by systematic study, and this experiment was devised to test the value of exercise, which seems to be one of the important factors forming the complex of domestication. The present investigation shows that at least in such organs as the brain, eyeballs, sex glands, hypophysis and suprarenals, the exercised Albinos show an approach to the Norway rat.

In conclusion, I may repeat that from the anatomical side the question of exercise is usually taken rather lightly in the case of man, nevertheless when we consider its striking effect on some of the organs of the rat, a further careful investigation of the subject, not only in the rat but in man also, seems certainly worth while, both from the general biological standpoint and for its bearing on hygiene.

CONCLUSIONS

1. The following determinations were made on exercised as compared with non-exercised rats: (1) External measurements; body and tail length and body weight. (2) Visceral organs; heart, kidneys, liver, lungs, spleen and alimentary tract. (3) Ductless glands; testes, ovaries, hypophysis, suprarenals, thyroid

and thymus. (4) Nervous system and sense organs; brain and spinal cord, and eyeballs.

2. The albino rats allowed to exercise in the revolving cages for 90 or 180 days show modifications in most of the organs. Among them, the following may be mentioned:

(a) The heart, kidneys and liver show an average excess of about 20 per cent, while the spleen shows a similar amount of deficiency.

(b) The brain weight shows an average excess of 4 per cent, while no change is noticed in the case of the spinal cord. (This result agrees with the observation of Donaldson '11).

(c) The ovaries give an excess of 84 per cent, while the testes give an excess of 12 per cent.

(d) The hypophysis, as well as the suprarenals, respond differently to exercise according to sex. Furthermore, these two organs show, as the result of exercise, an approach to the relations characteristic for the Norway rat.

(e) The exercised rats were either entirely free from lung infection or but slightly affected. The control rats, on the other hand, had badly infected lungs and in some series several of them were lost, presumably from the lung disease. Analysis of the data shows that the lung infection is not responsible for the changes observed in the organs.

3. Exercise for the period of 30 days showed in most organs modifications similar to those observed in rats exercised for 90 to 180 days.

4. In the exercised rats the heart weight and amount of exercise taken are highly correlated.

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