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RATE OF GROWTH AND LENGTH OF LIFE

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Previously we have recorded[1,2,3] experiments in which, starting with a diet already adequate to the maintenance of normal nutrition and health for generation after generation, an improvement of this diet, by better quantitative adjustment of the natural foods of which it is composed, results in an increased rate and efficiency of growth, a higher level and longer period of adult vitality, and an extension of the average length of life and of the life-expectation of the adult.

More recently, McCay and Crowell,[4] in a different type of experiment, find that restricted as contrasted with maximal growth may also be followed by longer life.

Under what conditions, then, may an increased rate of growth be expected to be followed by longer life as in our previous work, when may an inverse relationship such as appears in McCay and Crowell's experiments be expected, and when do rate of growth and length of life vary independently?

The present paper deals with the differences observed within groups which were homogeneous in the sense of involving no known or experimentally controllable variable. In other words, it deals with the individual variations among laboratory rats of initial good health, of the same heredity, living in the same environment, and subsisting upon one or the other, respectively, of the two normal diets described in our previous papers as Diet A (which was adequate in the sense explained) and Diet B (which proved to be better). Animals on these two diets are here treated separately, and the records of the two sexes are separate; so that we are here dealing with differences which are not attributable to any other variable than such as, on the one hand, individual "growth impulse" and on the other hand, individual "constitution predisposing to longer life." Do these vary interdependently, or independently?

Plainly this is a different problem from that presented by experimentally induced nutritional differences; but one which bears upon the interpretation of the findings of the food experiments.

TABLE 1

LENGTH OF LIFE ON RATE OF GROWTH: HALVES OF "HOMOGENEOUS" GROUPS. AVERAGES WITH THEIR PROBABLE ERRORS

	MALES		FEMALES	
	DIET A	DIET B	DIET A	DIET B
Number of cases	135	124	196	163
Gain during 5th–8th weeks of life (inclusive)				
Slower-growing half—Gm.	43.9 ± 1.00	76.0 ± 1.24	39.0 ± 0.93	60.6 ± 0.65
Faster-growing half—Gm.	79.8 ± 1.08	107.0 ± 0.88	67.5 ± 0.42	79.8 ± 0.41
Difference with its P. E.	35.9 ± 1.47	31.0 ± 1.52	28.5 ± 1.02	19.2 ± 0.77
Ratio of difference to its P. E.	24.4	20.4	27.9	24.9
Average age at natural death				
Slower-growing half—Days	576 ± 12.5	618 ± 13.6	591 ± 12.9	677 ± 11.3
Faster-growing half—Days	567 ± 9.7	646 ± 10.3	616 ± 8.9	664 ± 10.7
Difference with its P. E.	−9 ± 15.8	+28 ± 17.0	+25 ± 15.7	−13 ± 15.5
Ratio of difference to its P. E.	−0.6	+1.6	+1.6	−0.8

Table 1 compares the average lengths of life of the slower-growing and faster-growing halves of each of the four "homogeneous" groups, i.e., of each sex on each of the two diets. We have recently shown[5] that the usual statistical interpretation is applicable with a high degree of accuracy to growth data of this type. Hence all four of the differences in rate of growth with which Table 1 deals are unquestionably significant as differences. Yet no relationship to the length of life subsequently attained by the same individuals appears; for in two of the four cases the greater average length of life was shown by the slower-growing, and in the other two by the faster-growing, half. In none of these four cases has the difference in rate of growth been followed by a difference in length of life which is statistically significant in the accepted interpretation of the term. And if we combine the findings of the four comparisons, taking account of sign, the apparent lack of relationship is strongly confirmed.

Further confirmation is afforded by comparison of the slowest-growing with the fastest-growing quarter of each of the four groups—the data of this comparison being here omitted in the interest of brevity.

Inasmuch as we have stronger evidence of the quantitative validity of the usual statistical interpretation as applied to rate of growth than as applied to length of life, the evidence of these findings becomes more strictly quantitative, and in this respect more convincing, when each of the same four "homogeneous" groups is divided into a shorter-lived and a longer-lived half and these then compared as to the rates at which they had grown. Table 2 summarizes the data as thus arranged. In only one of the four comparisons would the difference in average rate of growth as between the longer-lived and shorter-lived of comparable individuals appear statistically significant if it stood alone. When account is taken of the four parallel findings with respect to the sign as well as to the probable error of each difference it appears that the difference as indicated by this experiment as a whole is only about one-fifth of its probable error and hence that the chances are more than 1000 to 1 that the variations in rate of growth and length of life are independent rather than interdependent.

TABLE 2

RATE OF GROWTH ON LENGTH OF LIFE: HALVES OF "HOMOGENEOUS" GROUPS. AVERAGES WITH THEIR PROBABLE ERRORS

	MALES		FEMALES	
	DIET A	DIET B	DIET A	DIET B
Number of cases	135	124	196	163
Age of shorter-lived half—Days	469 ± 9.2	532 ± 10.5	475 ± 8.5	555 ± 8.1
Age of longer-lived half—Days	665 ± 5.5	735 ± 5.7	732 ± 5.5	786 ± 5.5
Difference with its P. E.	196 ± 10.7	203 ± 11.9	257 ± 10.1	231 ± 9.8
Ratio of difference to its P. E.	18.3	17.1	25.4	23.5
Growth in grams during 5th–8th weeks (incl.) of life				
Shorter-lived half	66.0 ± 1.91	89.8 ± 1.85	51.8 ± 1.26	69.4 ± 1.02
Longer-lived half	57.8 ± 1.58	93.1 ± 1.53	54.6 ± 1.14	70.9 ± 0.73
Difference ± P. E.	−8.2 ± 2.48	+3.3 ± 2.4	+2.8 ± 1.70	+1.5 ± 1.25
Ratio of difference to its P. E.	−3.3	+1.4	+1.6	+1.2

If the one case in which the difference which might superficially appear to be significant were more than accidental it should be confirmed and accentuated (and other cases might then also appear) upon comparing the data for the shortest-lived and longest-lived quarters of each of the same four groups. This is done in Table 3; and these findings confirm the more comprehensive view of the data of Table 2, for here none of the differences appears even superficially significant, the difference for the comparison as a whole is again only about one-fifth of its probable error, and (stronger evidence that these differences are only accidental) the *sign* of the difference is here reversed.

TABLE 3

RATE OF GROWTH ON LENGTH OF LIFE: FIRST AND FOURTH QUARTERS OF "HOMOGENEOUS" GROUPS.

AVERAGES WITH THEIR PROBABLE ERRORS

	MALES		FEMALES	
	DIET A	DIET B	DIET A	DIET B
Age of shortest-lived quarter, Days	389 ± 12.7	453 ± 15.6	386 ± 11.7	469 ± 10.0
Age of longest-lived quarter, Days	730 ± 5.7	784 ± 7.1	796 ± 6.5	842 ± 6.9
Difference ± its P. E.	341 ± 13.9	331 ± 17.2	410 ± 13.4	373 ± 12.1
Ratio of difference to its P. E.	24.5	19.2	30.6	30.8
Growth in grams during 5th to 8th weeks (incl.) of life				
Shortest-lived quarter	65.7 ± 3.17	91.4 ± 2.97	50.7 ± 1.80	70.1 ± 1.33
Longest-lived quarter	60.8 ± 2.19	96.1 ± 1.87	49.6 ± 1.87	69.6 ± 1.05
Difference ± its P. E.	−4.9 ± 3.86	+4.7 ± 3.51	−1.1 ± 2.59	−0.5 ± 1.69
Ratio of difference to its P. E.	−1.3	+1.3	−0.4	−0.3

When the longer- and shorter-lived halves or quarters are compared as to their growth in the portion of the life cycle preceding that used in the above comparison, it again appears that among the individuals of such a homogeneous group, rate of growth and length of life vary independently of each other.

An expression of the final outcome of all our comparisons of the longer-lived with the shorter-lived individuals of the same sex on the same diet indicates that the difference, if any, in rate of growth between the longer-lived and the shorter-lived was only about one-fifth its probable error; which, in view of previous statistical study of such growth data, may be interpreted as showing clearly that rate of growth and length of life here vary independently of each other. Or, differently stated, among individuals of the same sex and the same heredity, on the *same normal* diet, those who grew faster and those who grew more slowly had equally good prospects of a long life.

It is *also* evident that certain differences in food may influence *both* the rate of growth and the length of life. Studies of the influence of food upon length of life, with related observations upon growth and health, are being continued with the coöperation of the Carnegie Corporation of New York and the Carnegie Institution of Washington.

[1] H. C. Sherman and H. L. Campbell, *Jour. Biol. Chem.*, **60**, 5–15 (1924).

[2] H. C. Sherman and H. L. Campbell, *Proc. Nat. Acad. Sci.*, **14**, 852–855 (1928).

[3] H. C. Sherman and H. L. Campbell, *Jour. Nutrition*, **2**, 415–417 (1930).

[4] C. M. McCay and M. F. Crowell, *Anat. Rec.*, **57**, No. 4, Suppl. p. 102 (1933); *Nutr. Abs. and Rev.*, **3**, 1119 (1934); *Sci. Mo.*, November (1934).

[5] H. C. Sherman and H. L. Campbell, *Proc. Nat. Acad. Sci.*, **20**, 413–416 (1934).

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*THE GRAPTOLITES OF THE SIMPSON GROUP OF OKLAHOMA**

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The older sedimentary formations of the Arbuckle Mountains of Oklahoma beginning with the oldest are: Reagan sandstone (Cambrian), Arbuckle limestone (Cambro-Ordovician), Simpson group, Viola limestone, Sylvan shale (all three Ordovician), Chimneyhill limestone and Henryhouse shale (both Silurian).

The Simpson group has been divided by the writer[1] into five formations, Joins, Oil Creek, McLish, Tulip Creek and Bromide. All five of these formations are present in the western part of the mountains, but the oldest and next to the youngest (Joins and Tulip Creek) wedge out in the middle part of the mountains, leaving only three formations in the eastern part.

In the formations named above, graptolites have been found in the Arbuckle, Joins, Bromide, Viola, Sylvan and Henryhouse. Considerable progress has been made recently on the study of the graptolites of these formations. They are listed by zones in a paper on the Viola limestone,[2] and thirty species and varieties from this formation have been described and illustrated.[3] Two more papers have been sent to press recently on the graptolites of the Henryhouse and Sylvan shales. Yet much remains to be done on the graptolites of the Arbuckle Mountains and on those in other formations in the eastern part of the State. The study thus far has yielded excellent results in local and in widespread correlation.

In the Simpson group graptolites have been found in only two horizons, one near the base in the lower part of the Joins formation, and one near the top in the upper part of the Bromide formation. The lower zone was found and traced around the mountains by the writer and Rex McGehee in 1928. Earlier Chester A. Reeds had found *Didymograptus artus* in this zone and had sent them to E. O. Ulrich,[4] who placed them provisionally in the upper part of the Arbuckle limestone.

As a rule *Didymograptus artus* was found in a zone only 2 inches wide, but in the Criner Hills it ranges through 8 feet of sediments. The zone was found to vary from 43 to 102 feet above the base of the Joins formation. It was found also 50 feet above the base of the Joins by D. A. McGee at