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Altered Growth of Animals After Continual Centrifugation[1]

CHARLES C. WUNDER[2]

Abstract. Two different animals have demonstrated an accelerated growth after prolonged centrifugation. This report is primarily concerned with larvae of the common fruit fly, *Drosophila melanogaster,* after 24 hour periods of centrifugation at fields between 2200 and 3300 G's. Similar studies are reported for the laboratory white mouse, *Mus musculus.* after seven days of centrifugation at 7 G's. The faster growth is possibly due to more efficient growth, resulting as an adaptation to greater gravity. Such a suggestion is supported by the finding that centrifuged larvae exhibit a reduced oxygen requirement for growth.

In recent years there have been several demonstrations that increased gravity will alter the growth of organisms (Matthews, 1955; Gray, 1955; Wunder, 1955; Kelley, 1957; Walters *et al.,* 1960). Increased gravity was artificially produced by continual centrifugation. When sufficiently intense, gravitational fields caused a decreased growth (Figure 1). However, moderate increases in gravity on some occasions actually stimulated rather than inhibited growth

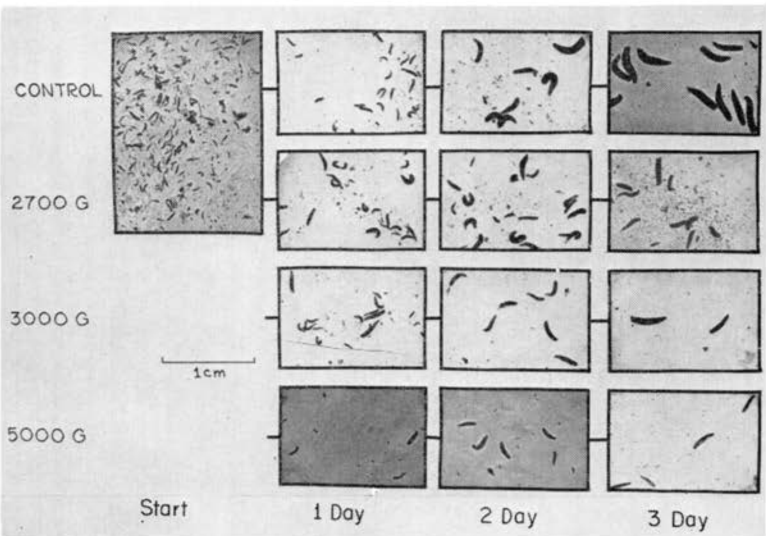

Figure 1. Shadow photographs of growing fruit fly larvae after different durations of centrifugation in centrifugal fields.

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(Gray and Edwards, 1955). It has been suggested that the decreased rate results from less food being available for growth processes. This, in turn, might be attributed to the diversion of food materials for work opposing gravity (Wunder, 1955) and to a decreased food consumption. To compensate for this effective reduction in food, it is quite possible that adaptation would involve a more efficient utilization of the food materials employed in growth and growth related processes. The greater growth which occurs in the centrifuge no doubt results from an over-compensation. Should this adaptation be permanent, a faster than normal growth would be expected upon return of the animal to control conditions. It is the purpose of this paper to report that under certain conditions this increased rate does occur.

It has been recognized for some time that normal gravity does stimulate the growth of plants (Knight, 1806). Gray and Edwards (1955) demonstrated an enhanced response to this field by centrifugation of wheat coleoptiles. Similar results have been obtained in our laboratory with mouse femur bones (Wunder, *et al.*, 1960).

Materials and Methods

Two animals were employed in this study: larvae of the common fruit fly, *Drosophila melanogaster* (wild, red-eyed strain), grown at 31.5° C, and the mouse, *Mus musculus* (albino, NLW strain), grown

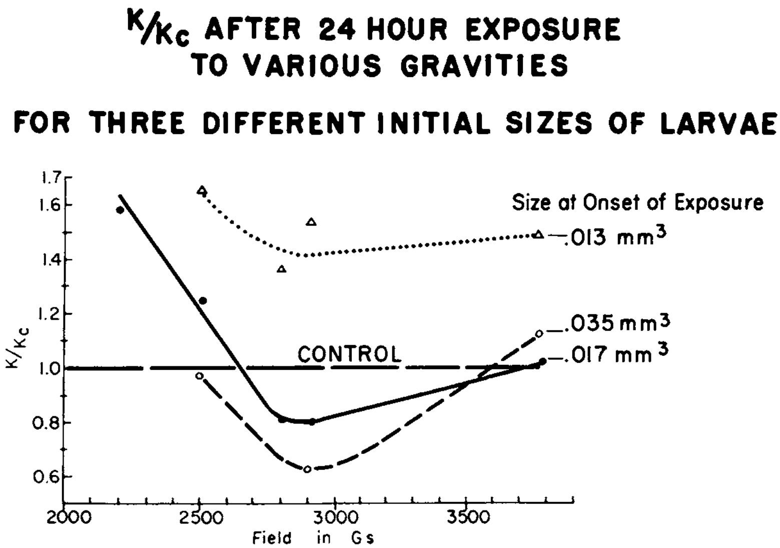

Figure 2. The experimental growth constant, k, relative to the control value, k_c, is shown. Thus the value of unity for these ratios represents the control ratio. Note that smaller larvae are the ones which will exhibit the fastest growth after centrifugation. The standard errors for these ratios are approximately one tenth of the magnitude of the ratios.

at 22° C. The techniques for centrifugation, care and growth analysis have been described elsewhere. The larvae were cultured upon a modified banana-agar medium with changes in volumes employed as a criterion for growth. As these organisms display exponential growth, the growth constant, k, which is the rate of change in the natural logarithm of size, can be used in comparing the growth rates for larvae of various sizes. Changes in body mass served as the growth criterion with mice.

After periods of continual centrifugation, which lasted one day with the larvae and one week with the mice, the animals were removed from the centrifuge and grown in normal gravity.

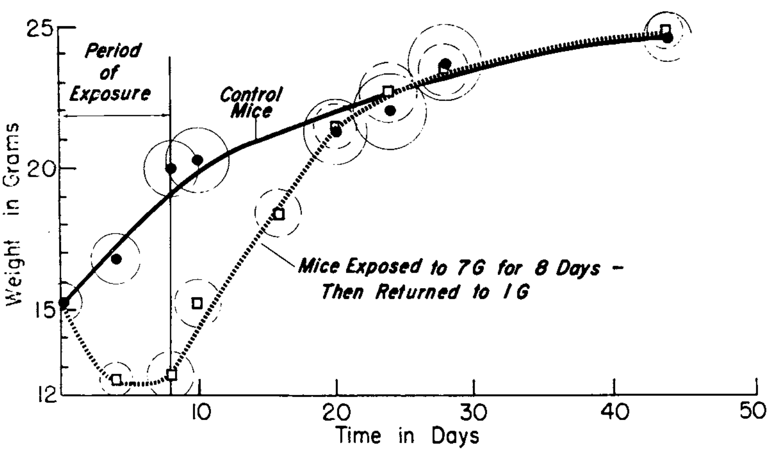

Figure 3. Accelerated growth of female mice after one week of centrifugation. The values are for 12 experimental and 12 control animals which were four weeks old at the onset of the experiment. Unfortunately, none of these mice could be kept at 7 G's for a longer period. However, with other similar experiments mice have remained at 7 G's for as long as one year with no such acceleration of growth after one week of exposure.

The symbol "G" will be employed for reference to multiples of the Earth's normal gravity. Standard error of values is indicated by the terms following a "±" sign, the radius of a circle about experimental points.

Results and Discussion

Whenever an animal was returned to normal gravity after centrifugation, growth proceeded faster than under experimental conditions. For freshly hatched larvae, centrifuged at from 2000 to 3000 G's, the growth was faster than normal (Figure 2). The same results were obtained with 5-week-old mice after centrifugation at 7 G's for one week. The mouse growth was accelerated until control size was attained. These mice, however, never actually exceeded the size of control animals (Figure 3).

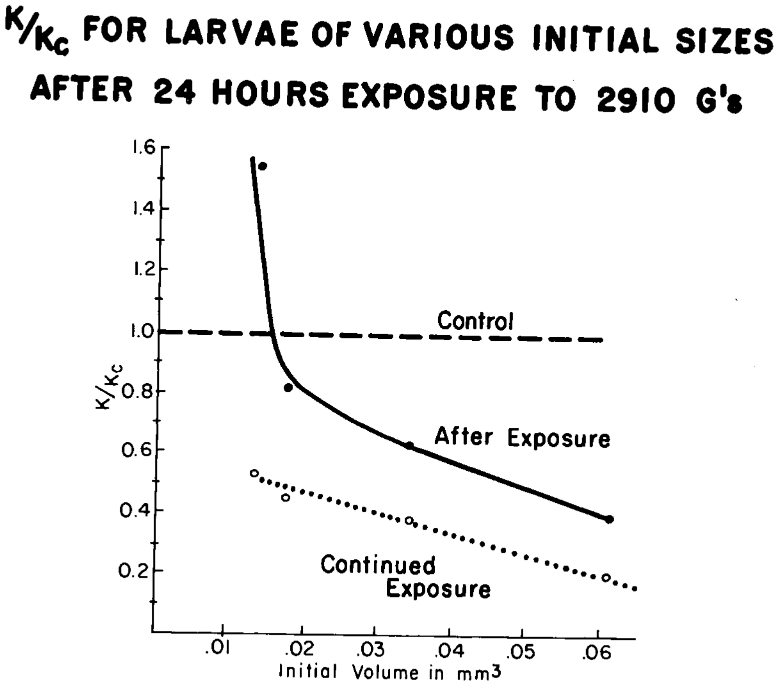

Figure 4. As with Figure 2, k represents the experimental growth constant and k_c the control value. Note that the animals which are the smallest at the onset of exposure have the greatest growth rate both during and after centrifugation. The standard errors for these ratios are approximately one tenth of the magnitude of the ratios.

With the larvae, the smaller the size at the onset of centrifugation the greater is the growth rate after return to control conditions (Figure 4). This is consistent with previous findings that the smaller the initial size, the faster is the development during centrifugation (Wunder *et al.,* 1959). For those exposed immediately after hatching, there was what appeared to be some over-compensation (Figure 5). After exposure to 2200 G's, the animals were at some times actually larger than the controls (Figure 6). There have been, however, no known cases where the size of any previously centrifuged animal exceeded that of the final or mature size of controls.

Various animals upon return to control gravity do, in spite of some faster growth, display detrimental effects of earlier centrifugation. The average larva never attains the size finally attained by the controls. Some will pupate, but the number that then emerge as adults is below normal. Kelly *et al.* (1957) reported that chickens at the cessation of centrifugation displayed a marked increase in mass but never equaled the size of control animals. This is similar to preliminary results obtained in our laboratory with mice after centrifugation at three and at five G's for a period of two weeks. A plausible explanation is that parts of the animal not needed for immediate physical growth are temporarily sacrificed as an adaptation to gravity. This adaptation may well result in a more efficient growth. This would at first be reflected by an accelerated development. On the other hand, if the gravitational stress persists for too long a period, certain structures could be permanently lost or atrophied. If the sacrificed material is not necessary until a later developmental stage, there would be an apparent delay in gravitational stress.

Studies of the oxygen consumption of fly larvae are underway in our laboratory. The findings to date agree with the concept of an increased efficiency (Wunder *et al.*, 1960). The experiments completed thus far are for larvae contrifuged at 20° C and at 28° C. In these studies, the larvae, after centrifugation, display a reduced

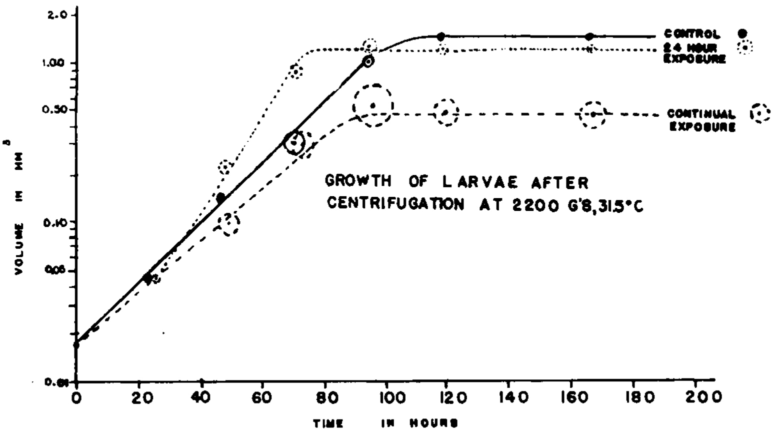

Figure 5. The dotted line is for animals removed from the centrifuge after 24 hours of centrifugation.

oxygen consumption. They continue to grow but the ratio of the oxygen consumed to the amount of larval tissue grown is reduced. At normal gravity, animals subjected to fields of from 1200 to 2400 G's display a reduction of approximately 40% in the amount of oxygen consumed during a given amount of growth. This is true both in instances where the centrifugation had drastically reduced the growth rate and in instances where there was no marked effect upon this rate. If we define efficiency for growth in terms of the ratio of increase in size to oxygen consumption, then there is an increased efficiency. Unfortunately, similar studies at 31.5° C or during acceleration of growth are incomplete. Nonetheless, an increased efficiency is the type of adaptation which could explain more rapid growth upon return to normal gravity.

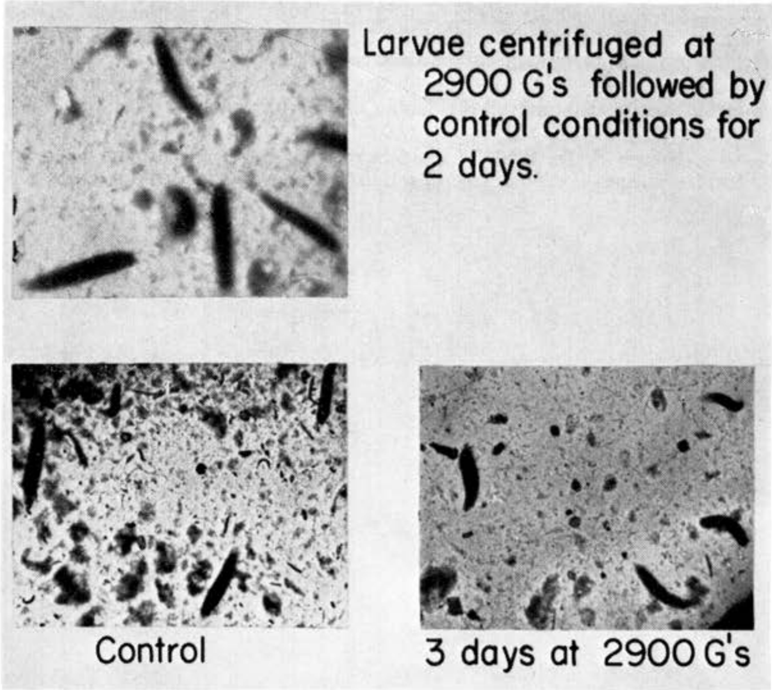

Figure 6. These shadow photographs are of the larvae whose growth curves are plotted in Figure 5.

Short periods of continual centrifugation, particularly with the smaller larvae, can cause some adaptation to gravity. An increased efficiency might explain why such animals upon return to normal conditions are able to grow at a faster rate. Prolonging centrifugation for even greater periods of time could well cause deteriorative effects which cannot be completely compensated for even upon return to control conditions.

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