GEOTROPIC CREEPING OF YOUNG RATS.

By G. PINCUS.

(From the Laboratory of General Physiology, Harvard University, Cambridge.)

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I.

The geotropic conduct of young rats has been discussed in a previous paper (Crozier and Pincus, 1926–27) with special reference to the angle of orientation upon an inclined plane. It was found that the angle of orientation \( \theta \) is directly proportional to the logarithm of the gravitational component \( g \sin \alpha \) in the creeping plane. This is explicable as the result of the distribution of the pull of the animal's weight upon the legs of the two sides of the body during progression, upward orientation being the result of the “pull” of the legs on one side and the upward “push” of the legs on the other side; when orientation is attained, the ratio of the tensions on the legs of the opposite sides is regarded as constant and the difference between these tensions as a constant fraction of the total downward pull.

To examine further the nature of the geotropic conduct of young rats, observations on the speed of upward creeping were undertaken. Cole (1925–27) has discussed similar observations on Helix; he concludes that the speed of movement, after orientation has been attained, varies as \( \sin \alpha \). But, as has been pointed out already (Crozier and Pincus, 1926–27), in these experiments the speed measured was that of vertical ascension, and no correction was made for the changes of \( \theta \) at the different angles of inclination; such changes occur in the orientation of gasteropods. Since, at lower angles of inclination of a creeping plane (15°–70°) the animal moves at an angle \( \theta \), it is necessary to multiply the time of upward creeping by the sine of the angle of orientation \( \theta \) in order that the amount of time actually necessary to cover a constant distance may be dealt with at each angle of inclination (cf. Fig. 1). In terms of Fig. 1, the rate of creeping is given by the
fraction $\frac{AB}{t \sin \theta}$, where $AB = 32$ cm., and $t$ is time in seconds. The required rates are therefore proportional to $\frac{1}{t \sin \theta}$.

II.

The rats used in these experiments were 13 to 14 days of age. As in the previous experiments, only animals with unopened eyes were used. To insure uniformity the animals employed were of the same age (litter mates), of known genetic constitution, and of the same weight. It was soon found that the animals show periods of activity followed by periods of inactivity, the latter being possibly due to or influenced by fatigue. Care was therefore taken to use only active individuals, and between tests each animal was allowed to rest for 20 to 30 minutes.

Observations were made in a dark room under red light of low intensity, at a temperature of $23^\circ$-$25^\circ$C. The animals were placed on a creeping plane of wood covered by fine meshed copper wire. A distance of 32 cm. was marked off on the creeping plane with white chalk, and by means of a stop-watch the time was taken for the animal to creep from one white line to another.
At least ten runs were made at each angle of inclination, and at 15° and 20° inclinations, where the speed is more variable, twenty runs were recorded.

III.

Table I contains: (a) the times for creeping between two lines 32 cm. apart (AB in Fig. 1) as obtained for various angles of inclination from 15°-60°, and (b) the corrected rates secured by multiplying the observed rates by the sine of the angle of orientation (θ) and taking the reciprocals. No records for inclination above 60° were taken because these young animals have not the muscular equipment necessary for uniform response to the more intense geotropic excitation of the higher angles of inclination. The speed of creeping, like the angle of orientation, varies directly as the logarithm of the angle of inclination (Fig. 2). Therefore the speed of creeping should be directly proportional to the angle of orientation (θ), and Fig. 3 shows that this is the case.

In a preceding paper (Crozier and Pincus, 1926-27) it has been shown that the precision of upwardly directed movement increases as the angle of inclination increases. That is, the reduction of variability (V) in the measurements of θ is proportional to the logarithm of the gravitational stimulus:

\[- V = K \log \sin \alpha.\]
FIG. 2. The rate of creeping expressed as $10/(t \times \sin \theta)$ is plotted against the logarithm of the active gravity component. A direct proportionality is observed, the spread of the points at the lower inclinations indicating the increase in variation with lower intensities of stimulation.

FIG. 3. The rate of creeping is plotted against the angle of orientation ($\theta$). Since both are directly proportional to the logarithm of the active gravity component it follows that they should be directly proportional. This is the case, and a check is had upon the relation expressed in Fig. 2.
This relation is plotted in Fig. 4 for the speed of creeping. The speed of creeping is a much more complicated thing than the simple geotropic orientation, and is influenced by unanalysed fatigue effects and by cycles of activity. Furthermore, only ten observations were taken at each inclination. Nevertheless, it is apparent that the variability in speed of creeping is less at higher angles of inclination than at the lower angles, and that the relationship is linear, as in the case of the amount of upward orientation.

Fig. 4. The "coefficient of variation," expressed by the probable error as per cent of the mean, is plotted against the logarithm of the active gravity component. The result indicates that the variability in the rate of creeping decreases as the angle of inclination (α) is increased, and in the same manner as the variability of the extent of upward orientation (Crozier and Pincus, 1926–27).

IV.

When weights are attached at the base of the tail of a young rat creeping on an inclined plane the angle of orientation increases approximately as the logarithm of the added weight (Crozier and Pincus, 1926–27). To test this relation further, the speed of creeping with attached weights was measured at two angles of inclination, 15° and 20°. Weights of 1.6, 2.6, 5.2, 7.0, and 9.8 gm. were used.
The angle of orientation (θ) with attached weights was measured as well as the rate of creeping, and correction of the rate was made by multiplying the observed times by sin θ, as before. The results are given in Table II. Fig. 5 gives the corrected rate plotted against the logarithm of the added weight and indicates a direct proportionality for the 20° inclination; at the 15° inclination the plot is apparently curvilinear. However, when, as in Fig. 6, the corrected rates are plotted against the angles of orientation (θ) the direct proportionality observed indicates that the curvilinear distribution in Fig. 5 for 15° is accidental.

The significance of these data lies in the fact that they demonstrate the proportionality of geotropic response to the logarithm of the active gravitational component, rather than to the gravitational intensity directly. They give further confirmation of the hypothesis that the geotropic responses are the result of the pull of the animal's weight on the legs of opposite sides. This makes it unnecessary, or indeed impossible, to account for the orientations in terms of the pull of the head upon the neck muscles. It may be emphasized that as the weight of the attached load is increased, or as the angle of inclination of the creeping plane is increased, the legs are actually further extended. The angle of orientation, however, seems to be determined by the difference in effective pull on the legs of the two sides, such that, diagrammatically, at orientation \((x - y) \cos \theta = KMg \sin \alpha\), where \(x\) and \(y\) represent the lever radii of the legs on the "down" and "up" sides.
Fig. 5. The rate of creeping with attached weights at two angles of inclination (15° and 20°) is plotted against the logarithm of the attached weight. At 20° the result indicates a direct proportionality. At 15° the result is apparently curvilinear, but this may be due to fortuitous variations in θ.

Fig. 6. The rate of creeping with attached weights at two angles of inclination (15° and 20°) is plotted against the observed angles of orientation at these angles of inclination. The result shows a direct proportionality; the curvilinear relation at 15°, as apparently indicated in Fig. 5, is not detectable.
of the body, respectively. If $KMg \sin \alpha$ be increased by adding a load to the rat's tail, $K$ remaining a constant and $M$ being the mass lifted, $(x - y) \cos \theta$ must increase, hence $(x - y)$ must become larger (since $\theta$ is increased); therefore the legs on the "up" side are further extended, relatively, than in the absence of added weight; this is a fact of observation. Thus the increase in $\theta$, with $\alpha$ constant, when a weight is added, results from the extension of the limbs by the added load, since the "upper" or $y$ limb is stretched and thus more extended. The speed of creeping in influenced in exactly the same way as the extent of orientation.

**SUMMARY.**

The rate of upward creeping in negatively geotropic rats aged 13 to 14 days is a function of the gravitational stimulus. The rate of upward movement on the creeping plane, like the angle of orientation, is directly proportional to the logarithm of the gravity component. The variability in the speed of creeping decreases in proportion to the logarithm of the gravitational effect. When weights are attached to the animals' tails the rate of upward creeping varies almost directly as the logarithm of the attached weight, and the speed of creeping is still proportional to the angle of upward orientation.

**CITATIONS.**