Reports

Avoidance "Conditioning" in Paramecia

Learning is usually assumed to be a property of multicellular organisms with central neural axes (beginning, in phylogeny, with the flatworm). However, Gelber (*1*) has reported that the one-celled paramecium can be "trained" to approach a platinum wire that has been associated with food. Jensen (*2*), on the other hand, concludes that the behavior in question may be explained in terms of uncontrolled changes in the water medium in which the paramecia are observed. The question at issue, therefore, is whether it is the paramecium or its environment that has been "conditioned."

The same issue was involved in a series of studies conducted in the 1930's on the ability of paramecia to benefit from experience in what might be termed an avoidance conditioning experiment. Bramstedt (*3*) studied paramecia in a half-light, half-dark, water-filled well. When the lighted half was heated and the dark half was cooled by external means, the paramecia tended to remain in the cool side. When the temperature of the two halves of the well was equalized, the animals continued to avoid the lighted, previously heated side. Bramstedt thus claimed to have demonstrated conditioning of the avoiding response to the stimulus of light, which does not ordinarily elicit this response. Grabowski (*4*), who repeated and extended Bramstedt's work, ran tests of animals under three conditions: a control for differential response to light, the light-heat "conditioning" situation, and a control for heat-induced changes in the water medium. Like Bramstedt, he reported light alone an ineffective stimulus to elicit avoidance. During "conditioning," Grabowski's animals avoided light when it was paired with heat and, for almost an hour after temperature equalization, spent considerably more time in the dark. In the heat-induced–change control condition, however, water which had been "conditioned" before the introduction of animals produced the same effect—paramecia avoided the previously heated side, although they had had no opportunity to form an association between light and heat. On the basis of the latter finding, Grabowski concluded that the "conditioning" in paramecia was an artifact of the technique: Paramecia avoided the previously heated side because it had a lower concentration of oxygen.

The investigation (*5*) described in this report was designed to provide other controls indicated in the Bramstedt-Grabowksi experiments which would aid in specifying the conditions under which the behavioral modification occurs. The first stage of this investigation was the replication of the three sets of experimental conditions described by Grabowski.

Thirty-four *Paramecium aurelia* (see Table 1) were observed individually in a half-lighted, half-darkened well-slide containing a well 17 mm in diameter by 3 mm in depth. The medium in which the animals were observed consisted of filtered wheat infusion. Six animals (light-control group) were observed for 10 minutes in the unheated infusion-filled well as controls for a differential response to light; 14 ("conditioning" group) were observed for at least 15 minutes after they had been subjected to a "conditioning" period of at least 40 minutes during which the lighted half of the well was heated and the darkened half was cooled from below, a gradient of from 80° to 105°F across the well being thus provided; 14 (O_2 control group) were observed for at least 15 minutes after they had been placed in an infusion-filled well in which the lighted half had previously been heated and the darkened half had been cooled for at least 40 minutes. The latter animals were placed in the well immediately after equalization of the temperature. The scores for several animals which remained motionless for all or most of the observation period have not been included.

During the "conditioning" procedure, all of the 14 animals avoided the heated side of the well, spending an average of only 2 minutes, 52 seconds (the range was from 1 minute, 9 seconds to 4 minutes, 39 seconds) out of the at least 40 minute "conditioning" period in the heated side. The average number of entrances into the heated side was 19.5 (range 8 to 40). Table 1 presents the mean proportion of time spent in the lighted side of the well by the animals in the various conditions. The mean proportions of time spent in the light by Grabowski's animals under similar conditions (calculated from Grabowski's data) are included for purposes of comparison. The data for the light-control group in each case are based on 10 minutes of observation; all other proportions are based on 15 minutes of observation. Table 2 presents the results of a weighted-mean-square analysis of variance (*6*) of the data of our study and of that of Grabowski.

The analysis of variance indicated that there was significant variance between experiments, between conditions, and, due to the interaction, between experiments and conditions (all at $p < .001$). The Dunnett t test (*7*) was used to make comparisons between the "conditioning" mean of our experiment and the other means. Neither of the control means of our experiment nor the light-control mean in Grabowski's experiment differed significantly from the "conditioning" mean in our experiment. The Scheffé test (*8*) was used for comparisons between means not involving the "conditioning" mean of our experiment. Although the

Table 1. Mean proportions of time spent in the light by *Paramecium aurelia* in the several conditions of the experiment discussed in this report and of that of Grabowski.

Item	Experimental group		
	Light control	O_2 control	"Conditioning"
Katz and Mirsky			
Time in light (%)	0.47	0.45	0.40
N	6	14	14
Grabowski			
Time in light (%)	0.46	0.14	0.10
N	19	4	8

Table 2. Analysis of variance of the data of the experiment discussed in this report and of that of Grabowski.

Source of variance	*df*	Mean square	*F*
Between experiments	1	0.5292	70.56*
Between conditions	2	0.2414	32.19*
Interaction of experiments × conditions	2	0.1227	16.36*
Error	59	0.0075	
Total	64		

* $p < .001$.

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light-control means of the two experiments do not differ, both the "conditioning" mean and the O_2 control mean in the Grabowski experiment are significantly lower ($p < .01$) than the corresponding means of our experiment. Although there was no significant difference between the O_2 control and the conditioning mean in the Grabowski experiment, both of these differed significantly ($p < .01$) from the light-control mean.

These comparisons demonstrate clearly that it was not possible to replicate the findings of Grabowski, except with respect to the proportion of time spent by the paramecia in the light in the light-control condition. Contrary to the results of Grabowski, neither conditioning the paramecia nor conditioning the water in our experiment produced any modification in the tendency of the animals to spend roughly equal amounts of time in the dark and light.

Some incidental observations made during the "conditioning" procedure may help to account for the difference in results. When the well was being differentially heated and cooled, a powerful convection current invariably accompanied the gradient in temperature—a current so powerful, in fact, that it often appeared to sweep an animal into the heated side of the well. The presence of the convection current under the conditions of our experiment would seem to rule out the possibility of there being an appreciable difference in oxygen concentration between the two sides of the 17 mm well in either the "conditioning" or the light-control situations. This is consistent with the finding of no significant difference among conditions in our experiment. If it is assumed that Grabowski was somehow able to avoid the presence of the convection current in his smaller 10 mm well (he makes no mention of convection), then the results of our study may be interpreted as supporting Grabowski's interpretation of the response modification of the paramecium in terms of environmental modification.

The results of our study and of those of Grabowski and of Jensen indicate that there has been no unequivocal demonstration of conditioning in paramecia, in either the food-approach or the heat-avoidance situations. Apparently, whenever the "learning" situation has been arranged so as to preclude the possibility of permanent or relatively permanent changes in the environment of the paramecium, then subsequent behavioral modifications have not been observed.

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References and Notes

1. B. Gelber. *J. Comp. and Physiol. Psychol.* 45, 58 (19: ➔ *Science* 126, 1340 (1957).
2. D. D. Jensen, *Science* 125, 191 (1957); 126, 1341 (1957).
3. F. Bramstedt, *Z. vergleich. Physiol.* 22, 490 (1935); *Zool. Anz. Suppl.* 12, 111 (1939).
4. U. Grabowski, *Z. Tierpsychol.* 2, 265 (1939).
5. This investigation was conducted at the City College of the College of the City of New York. We thank Professors J. E. Barmack and H. G. Birch for their guidance and suggestions and Samuel Greenhouse, National Institute of Mental Health, for advice on the statistical treatment of the data.
6. G. W. Snedecor, *Statistical Methods* (Iowa State College Press, Ames, 1946), p. 299.
7. C. W. Dunnett, *J. Am. Statist. Assoc.* 50, 1096 (1955).
8. H. Scheffé, *Biometrika* 40, 87 (1953).

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Fall of the Sputnik I Rocket

There has been considerable interest in the matter of determining the probable point of impact of artificial satellites (*1*). We are conducting a study of the behavior of satellites as they reenter the atmosphere during the final phase of their lifetimes, and in this connection we have examined the data on satellite 1957 Alpha 1, the carrier rocket which accompanied Sputnik I.

Our calculations lead us to the conclusion that 1957 Alpha 1 fell on 1 December 1957 at 0846 G.M.T., approximately 8 hours after the last radar observation made on it in the United States. We place the probable point of impact at latitude 45°N, longitude 106°E, in Outer Mongolia. The result of our investigation is shown in Fig. 1, which represents the trajectory of 1957 Alpha 1 during its final pass over the Northern Hemisphere. The probable impact point is marked by a circle in Fig. 1, and the uncertainty in the impact point by heavy lines to either side of this circle.

The analysis is based on several observations of the altitude of the satellite during the last five days of its lifetime. These altitudes were deduced from radar observations of 1957 Alpha 1 obtained by: (i) the Lincoln Laboratory (*2*) on 27 November at 2153 G.M.T., 29 November at 2137 G.M.T., and 30 November at 1944 G.M.T. and 2114 G.M.T.; (ii) the Stanford Research Institute (*3*) on 1 December at 0011 G.M.T.; and (iii) the staff of the Royal Radar Establishment (RRE) (*4*) at Malvern, England, on 1 December at 0828 G.M.T.

The altitudes obtained from these radar sightings are indicated in Fig. 2. Figure 2 also shows the calculated altitudes, determined by us from a numerical integration of the satellite equations of motion, starting with orbital data provided by the Smithsonian Astrophysical Observatory for the date of 11 November 1957. The calculated altitudes in Fig. 2 are seen to be in good agreement with the observed altitudes for all passes.

The penultimate measurement shown in Fig. 2 was taken on the Stanford radar during the final pass of the satellite over the United States. The last datum in Fig. 2 is that of the RRE radar at Malvern, obtained, as already noted, at 0828 G.M.T. It is interesting to note that even if both of these data are omitted, the comparison of the remaining observations with our calculated altitudes indicates that the satellite could not have fallen during its last pass over the continental United States, nor in fact for several passes thereafter. For if we assume the last pass in the lifetime of the satellite to be that in which it crossed the western United States, the calculated altitudes then fall on the dashed curve of Fig. 2. The differences between this curve and the data are well outside the probable errors for the observations. In our view, Fig. 2 provides conclusive evidence that the satellite continued on for approximately 8 hours beyond the pass over the west coast of the United States.

The last datum point in Fig. 2 is an altitude of 71 miles, obtained by the RRE radar. This observation is critical for the unambiguous determination of the impact point. An altitude as low as 71 miles indicates that at the time of the passage over Malvern the rocket had entered on the final dive of its reentry into the atmosphere. The detailed numerical integrations then indicate that the rocket continued on past Malvern for 64° in the plane of the orbit before striking the earth. This figure of 64° is subject to an uncertainty of ± 15°, corresponding to the probable error in the altitude of the RRE observations, and

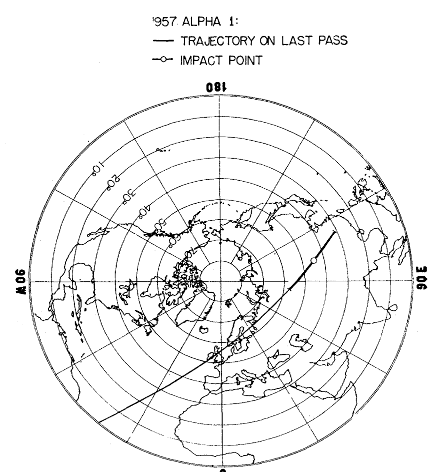

Fig. 1. Polar projection of the Northern Hemisphere showing the trajectory of satellite 1957 Alpha 1 during its final pass. The calculated impact point is indicated by a circle at latitude 45°N, longitude 106°E. The probable error in the impact point due to uncertainties in (i) the altitude over Malvern, England, and (ii) the drag coefficient is indicated with heavy lines to either side of this circle.