238 ml/min per kilogram. In a series of 14 animals where 15 assays of cardiac output in each animal at 2-minute intervals were measured in serial succession, the animal of widest variation was ±6 percent from the mean output of 133 ml/min, ranging from 126 to 141 ml/min, which demonstrates considerable reliability for the method.

In a more critical series of serial assays, 63 successive measurements of cardiac output were made at 2-minute intervals in each rat. The average cardiac output was 249 ml/min per kilogram, and the maximum range from the mean for each animal was ±9 percent, with a standard deviation of 6 percent. The last seven assays per animal showed a cardiac output per animal only 4 percent greater than the output on the initial seven assays; the difference was not significant. With our method, only about 3 ml of saline were added to the circulating blood during more than 2 hours. The values compare favorably with those of our other series and with other techniques (*4*).

A practical feature of this circuit is that it can be balanced to any temperature within physiologic range, including hyperthermia. To demonstrate the ability to measure under normal and hyperthermic conditions, we studied 28 rats before and after exposure to 2450-Mcy microwaves. Individual exposures were maintained until rectal temperatures were increased to 40°, 40.5°, and 41°C. Each animal served as his own control and three measurements were made before and after each thermogenic irradiation. The data are summarized in Table 1. The average cardiac output increased 26 percent at 40°C, 65 percent at 40.5°C (demonstrating the highest elevation of output), and 47 percent at 41°C. These three separate conditions were significantly different at a 1-percent level of confidence or better. The heart rate and arterial blood pulse pressures were also elevated above the control level in the three hyperthermic conditions.

Table 1. Effects of microwave hyperthermia on cardiac output of albino rats. The rats weighed 370 to 530 g. Cardiac output is expressed in ml/min per kilogram of body weight.

	Control rats	Experimental rats	Increase (%)
	Rectal temperature 40.0°C		
	221	273	23
	226	283	25
	263	343	30
	240	304	27
	244	295	21
	208	268	29
	214	269	27
	242	302	25
Av.	232	292	26
	Rectal temperature 40.5°C		
	228	400	75
	196	332	68
	226	336	49
	227	422	86
	224	346	55
	229	393	71
	267	420	57
	268	429	60
	275	459	67
	245	418	71
	268	434	62
	269	426	58
Av.	242	401	65
	Rectal temperature 41.0°C		
	249	357	43
	232	381	64
	247	362	46
	248	344	39
	254	360	42
	224	362	61
	268	386	44
	234	326	39
Av.	244	359	47

To further test accuracy and reliability, we constructed a physical system so that saline at 37°C flowed by an injection site for room-temperature saline, with a sensing thermistor downstream to measure flow rate by thermodilution, the latter being calibrated by a graduated cylinder receptacle. With an average fluid flow of 34.9 ml/min, the measured flow by our thermodilution was 35.1 ml/min, a difference of 0.2 ml/min, or 0.6 percent, which was not significant.

The described thermodilution method is practical to measure cardiac outflow in very small animals, being sensitive, accurate, and reliable. It offers the new possibility of numerous successive assays in the same animal, is practical for larger animals such as dog and man, and is inherently safe to employ (*5*).

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All-or-None versus Incremental Learning of Errorless Shock Escapes by the Rat

Abstract. Investigation showed that in a two-choice correction procedure the probability of an errorless response in those rats which have consistently made errors is not constant, as required by the all-or-none model, but increases with trials. Even an all-or-none model which provides for accidental error and accidental success is inadequate.

The growth function of Hullian and more recent linear models of learning assumes that successive reinforcements add increments of probability of response which are a constant fraction of what potentially remains to be learned, that is,

$$P_{n+1} - P_n = \theta(a - P_n),$$

where θ is a constant and a is the asymptotic value approached by P_n. The solution of this difference equation is given by

$$P_{n+1} = a - a(1 - \theta)^n$$

for $i = 0, 1, 2, \ldots, n$. Such a function adequately describes group data, for example, proportions of subjects succeeding on each successive trial (for instance, see Table 1), but the fit to individual data has been questioned. The behavior of individual subjects may be more consistent with a discontinuous all-or-none principle, each successive trial affording the same, constant probability of a subject's forming the appropriate habit. The proportion of subjects with their first conditioned eyelid response, and first correct paired associate, remains constant from trial to trial (*1*). However, these data came from human subjects. It is possible that this flip-flop nature of the probability of success might be peculiar to thinking and talking subjects: eyelid and verbal responses may develop with positive feedback, similar to the feedback provided for the galvanic skin response (*2*). To test this possibility we examined the conditioning of rats, which appear to have at most only one postural symbol or idea at any given time (*3*).

In experiment 1, 112 Sprague Dawley and hooded rats were individually restrained with their heads extending over photoelectric cells (*4*). Shock current (a-c) through the tail was increased toward a maximum of 5 ma (*5*). As soon as the head position became more than 50 deg to the left or the right of center, the photocells

Table 1. Number and percentage of successes on each trial for the entire sample of experiment 1 and theoretical probabilities obtained by least squares. The ith trial occurs after the ith reinforcement; the theoretical probabilities were calculated with the least squares equation $P_{n+1} = 0.902 - 0.902(1 - 0.513)^n$.

Trial	No. of successes	Percentage of successes	Theoretical percentages
0	2	1.8	0
1	50	44.6	46.3
2	82	73.2	68.8
3	87	77.7	79.8
4	94	83.9	85.1
5	95	84.8	87.7
6	99	88.3	89.0
7	100	89.2	89.6
8	105	93.8	89.9
9	106	94.6	90.0

were connected so that this first and all subsequent shocks could be terminated only by 50 deg head position toward the opposite side. Subsequent shocks were started at 1-minute intervals. If, during any shock, the head was over 50 deg on the opposite side from the position which terminated shock, a failure was recorded for that trial. If a shock was terminated without error, a success was recorded. Ten trials were administered.

Experiments 2 and 3 were similar, except that they utilized 96 Wistar and Sprague Dawley female rats and 96 male Sprague Dawley rats, respectively. Twenty trials were administered in experiments 2 and 3.

The fact that our data are consistent with the model which assumes that each reinforcement adds an increment of probability of response which is a constant fraction of what potentially remains to be learned is exhibited in Table 1. Here a least squares fit is obtained for the data of experiment 1, yielding $a = 0.90$ and $\theta = 0.513$ for the parameters of the linear model. Similarly close fits may be obtained for experiments 2 and 3. On the other hand, it will be shown that our data are not consistent with an all-or-none model in which α is the probability that an animal which has not learned succeeds by chance, β is the probability that an animal which has learned fails by chance, and P is the constant probability of completely learning after any one reinforcement. By summing all possible ways that success can occur for the first time on the nth trial, we obtain the following expression for Q_n, the probability that the first success occurs on the nth trial:

$$Q_n = P\beta^{n-1}(1-\beta) + (1-P)(1-\alpha)P\beta^{n-2}(1-\beta) + \ldots + (1-P)^{n-1}(1-\alpha)^{n-1}P(1-\beta) + (1-P)^n(1-\alpha)^{n-1}\alpha$$

$$= \frac{P(1-\beta)}{(1-P)(1-\alpha)-\beta}\left\{[(1-P)(1-\alpha)]^n - \beta^n\right\} + (1-P)^n(1-\alpha)^{n-1}\alpha$$

In particular,

$$Q_1 = P(1-\beta) + (1-P)\alpha$$

$$Q_2 = P(1-\beta)[\beta + (1-P)(1-\alpha)] + (1-P)^2(1-\alpha)\alpha$$

Since Q_2 is almost as large as Q_1 in each of the three experiments (see Table 2), there are no values of the parameters α, β, and P which provide a reasonably good fit to these points. It follows from the model equation that the first two points will be equal only if α is small and if the value of P is close to that of β. This discrepancy between the model and the observed data is illustrated in Table 2, where the column 6 contains theoretical values of Q_n calculated with $\alpha = 0.00$, $\beta = 0.06$ (the mean probability of failure on trials 10–19 in experiments 2 and 3), and $P = 0.50$ (the approximate value of θ in the least squares fit to group data in Table 1). This provided the best fit among several attempts performed with a desk calculator.

Table 2. Percentage of animals achieving their *first* success on each trial and theoretical values for all-or-none model. The ith trial occurs after the ith reinforcement; the theoretical values were calculated for $\alpha = 0.00$, $\beta = 0.06$ and $P = 0.50$.

Trial	Experiment			Mean	Theoretical values
	1	2	3		
1	44.6	37.5	47.9	43.5	47.0
2	35.0	33.5	36.4	34.8	26.3
3	10.7	19.8	9.4	13.2	13.4
4	5.4	4.2	5.2	4.9	6.7
5	2.7	1.0	0.0	1.3	3.3
6	0.0	3.1		1.0	1.7
7		0.0			0.8

It may also be seen from Table 2 that there is an increase in the proportion of initial successes in rats which have previously failed. This is consistent with the linear model mentioned above. The constant proportions previously reported may be due to utilization of more complex human subjects, to a high initial probability P_0, and/or to a rate of conditioning θ so low as to have negligible effect over the short series of trials reported by Estes (*1*). The all-or-none model could perhaps describe our data if we assume that P is not constant. This is reasonable in view of the shock escape situation which necessarily provides different amounts of shock on successive trials.

Corresponding to the modifications suggested in the preceding paragraph, more general models are being investigated. One of the major purposes of this note is to point out that the constant probability, all-or-none model, which has been widely advocated, is not appropriate to our experimental data (*6*).

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Direct Determination of Density of Solids

Abstract. A method and apparatus for directly determining the density of solids is described. Essentially, density is determind by simultaneous measurement of the solid's volume by liquid displacement and of its weight by liquid head increase.

Standard laboratory methods to determine the density of an irregular insoluble solid are based on the measurement of liquid displacement upon total immersion to determine volume and on the use of a balance to determine weight. Procedures which can be adapted for field work utilize sink-float determinations in liquids of appropriate densities (*1*). A simple but effective way of determining the density of solids in one rapid operation with a portable unit has been devised in our laboratories.

When a solid is immersed in a liquid, it displaces a volume of liquid equal to its volume. A solid floating between two liquids, one heavier and one lighter than the solid, displaces the weight of heavy liquid equal to its weight corrected for buoyancy of the solid in the lighter liquid. Thus, if a solid is placed in a cylinder containing two liquids, one with a density greater than and one with