

# PREFERENCES AND DEMANDS OF THE WHITE RAT FOR FOOD

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The following series of experiments was carried out during the years 1932-5 to throw light upon the nature of food preferences and food demands of the white rat. The experiments will be considered in chronological order because the argument back of them developed gradually.

Following is an outline of the presentation:

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## I. SPATIAL FACTORS IN THE FEEDING BEHAVIOR OF RATS

### *Size and preference*

The larger of two food-objects is the more obtrusive to the eye and also mechanically to touch; in free movement of the animal the larger is more likely to be encountered than the smaller. *Size* of food-object is a spatial factor which may determine behavior in a purely mechanical way without any discrimination on the part of the animal.

Yoshioka<sup>1</sup> discovered that wild rats which accidentally reached

<sup>1</sup> J. G. Yoshioka, *Size preference of wild rats*, *J. Genet. Psychol.*, 1930, 37, 159-62; *Size preference of albino rats*, *ibid.*, 427-30.

a supply of sunflower seeds ate the largest seeds and left the smallest. The fact confirmed our previous finding that the larger of two grains is, on the average, likely to be eaten prior to the smaller.<sup>2</sup> We interpreted the fact in terms of mechanical, non-preferential factors and concluded that the preference of wheat to oats is relatively independent of size of the grain. Yoshioka, by contrast, claimed that there was a true preference for large size.

In a control experiment with twenty-one rats he demonstrated that the animals tended to select the largest sunflower seeds on the basis of visual size. The tendency to select the largest grains vanished in the dark, which fact indicates a visual rather than a mechanical basis of selection.

Yoshioka interpreted the finding in terms of preference for large size, whereas we had previously explained it in mechanical terms without implying any true discrimination between sizes. The two views are both true and supplementary. Preferential discrimination based upon size sometimes does occur; but size, position, and other spatial factors sometimes determine feeding behavior in a purely mechanical manner which is entirely free from discrimination and choice.

From the practical point of view, the factor of size is balanced out by the food preference technique through presenting foods in glass tubes of precisely the same diameter.

#### *Position and preference*

The more strongly determined an animal is to eat his food at a given place, either at the right or left of our apparatus, the less does he reveal true preferential discrimination between foods. In other words, spatially-determined behavior is antagonistic to preferential discrimination.

As a matter of fact, rats reveal their preferences only at certain times and under certain conditions. When an animal is not making preferential discriminations he probably is taking the food, regardless of its quality, at a given place.

<sup>2</sup> P. T. Young, Preferential discrimination of the white rat for different kinds of grain, *Amer. J. Psychol.*, 1928, 40, 381.

One feature of our food-preference technique<sup>3</sup> is the systematic interchange of positions of the two test-foods. For example, if wheat and sugar are being tested, wheat is presented at the right and sugar at the left on odd numbered trials; and *vice versa* on even.<sup>4</sup>

It occurred to us that any means of reducing the influence of spatial factors in the selection of food should aid in revealing the true preferences of an animal. With this point in mind we tried out several schemes for controlling spatial factors in the preference experiment. The main results of these attempts are recorded below.

*Preliminary observations upon spatially-determined behavior*

Eight rats, about three months old at the start of the work, which had been reared upon a standard laboratory diet,<sup>5</sup> were thoroughly habituated to the preference apparatus. Each animal was then given fifty trials (25 per day) with wheat in *both* tubes. Inasmuch as the wheat was taken from one and the same source of supply, discrimination on the basis of *kind* of food was ruled out. To guard against irregularities in the apparatus the standard procedure of interchanging positions of the tubes on alternate trials was followed. Our aim was simply to observe the spatial behavior of the rats with respect to right and left tubes when discrimination between foods could not exist.

The results are summarized below:

One rat (male, no. 23) ate the food contained in the right tube during every trial of the fifty. Another (male, no. 25) ate the food at the left consistently for the fifty trials. The other animals ranged between these extremes.

One animal (female, no. 32), who was the most free of all from spatial dominance, took the food at the right 26 times and that at the left 23;

<sup>3</sup> P. T. Young, Relative food preferences of the white rat, *J. Comp. Psychol.*, 1932, 14, 297; 1933, 15, 149.

<sup>4</sup> It has been suggested that this orderly interchange of positions favors the building up of an alternation habit; but if such a habit is built up, the fact itself is evidence for preferential discrimination, e.g., favoring sugar rather than wheat. Why should an alternation habit be developed which favors one food rather than another?

<sup>5</sup> *J. Comp. Psychol.*, 1933, 15, 150.

once she started to eat at the right and turned left. It would be difficult to find an animal freer than this last one from a definite spatial bias.

The five remaining animals showed varying amounts of sampling behavior—nibbling first the food in one tube and then in the other—a pattern which we have designated "alternate eating."

The following summarizes the behavior of two animals:

*No. 30, female*

Ate food on left.....	27 times
Ate food on left and then that on right.....	17 times
Sniffed or nibbled food on left then ate that on right.....	6 times

*No. 31, female*

Ate or nibbled food on left then that on right.....	24 times
Ate food on left.....	9 times
Ate food on right.....	14 times
Ate or nibbled food on right then that on left.....	3 times

The other three animals (males, no. 22 and 24; female, no. 28) were similar to the above two; they also, as it happened, favored the left position.

During the experiment the peculiar manner of approach to the food-tubes was observed for each animal. No. 22 approached rapidly and at such an angle that his head passed directly over the left food-cup and on to the right. He repeatedly began eating at the right cup without touching the left. Several animals approached the test-foods directly, but changed their bodily posture while eating. One walked slowly around the cups as he ate, constantly oriented toward the food; gross changes in posture controlled the position of his head with respect to the test-foods.

The general result of these observations is that individual rats differ markedly in the spatial aspect of their behavior. The patterns of eating must be referred to individual animals rather than to the apparatus. With the same apparatus one animal is wholly right dominant, another wholly left, another relatively free from either bias, etc.

To this conclusion we add a fact which we previously noted:<sup>6</sup> the animal is not wholly consistent from day to day in his spatial habits; on one day he may take the food at his right and on

<sup>6</sup> *J. Comp. Psychol.*, 1932, 14, 302-3.

another that at his left. It is not likely, therefore, that any fixed apparatus can be made which will entirely eliminate the space factor for all rats at all times. The rat must be treated as an individual.

*Control of the rat's approach to the test-foods*

In the regular procedure a rat is trained to leave the starting-box (*B*), fig. 1, through a door (*D*), and pass over a runway (*R*) to the feeding-plate (*P*) in the center of which are two food containers. The purpose of the runway is to guarantee that the

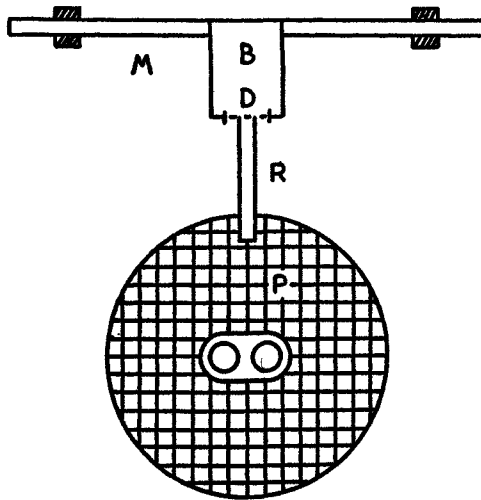


FIG. 1. MODIFIED PREFERENCE APPARATUS FOR CONTROLLING THE PATH OF APPROACH TO THE TEST-FOODS

animal will approach the test-foods always from the same point in space, and from a point that does not favor either right or left position.

The plan which we followed was to keep the runway centered, as illustrated in figure 1, until a rat had demonstrated spatially-dominant behavior, and then to move the runway gradually (between trials) in a direction counter to the spatial dominance. For example, if, during a preference test, a rat persisted in eating the food at his right, the runway was shifted between trials bit by bit to the left. We hoped in this way to counteract spatially-

dominant behavior and to force the rat to reveal his true preference between the test-foods.

To control the adjustments of the runway the starting-box was firmly attached to a meter stick (*M*), the latter being placed in guide blocks so that it could be slid to the right or left as required. The displacements were measured in mm. and recorded.

Tests were made: (a) with wheat in both tubes; (b) with several pairs of different test-foods.

Results are somewhat haphazard and unsystematic because we were constantly trying to counteract idiosyncrasies of individual rats; but one or two qualitative results are of theoretical importance.

A rat (male, no. 23) with pronounced right dominance in his feeding behavior persisted in taking the food at his right after the runway had been displaced more than six cm. to the left. Another (male, no. 25) with marked left dominance persisted in eating from the left tube when the runway was displaced more than six cm. to the right. These observations were with wheat in both tubes. The result agrees with the evidence that spatially-determined behavior depends upon some factor within the rat and not upon the apparatus.

Sometimes, with a pair of foods, our attempt to eliminate spatial dominance was followed by the sudden appearance of a definite food preference. We had the impression that we had *forced* the animal to make preferential discriminations when he was not inclined to do so. But obviously those preferential discriminations might have appeared had we not changed the apparatus; and we have no way of knowing without an extended experiment just how far our manipulation of the apparatus really caused the food preferences to appear.

Repeatedly we were able to change consistent right dominance into left dominance and *vice versa* without causing the animal to make preferential discriminations. In the present experiment it is clear that "right" and "left" are of uncertain meaning. That is to say, an animal eating consistently from the right tube could be made to eat consistently from the left simply by sliding the runway; but he continued to take the most accessible food

without showing any preferential discrimination between the two.

*Control of the angular position of the food containers relative to the line of approach*

Another scheme to control the factor of position is illustrated in figure 2. The runway was throughout centered upon the food-containers as in our standard procedure, figure 2-A, but the angle to the path of approach, made by a line through the food-tubes, was varied.

The argument behind the plan is direct and obvious. The foods, arranged as in *A*, are in equally prominent positions; but

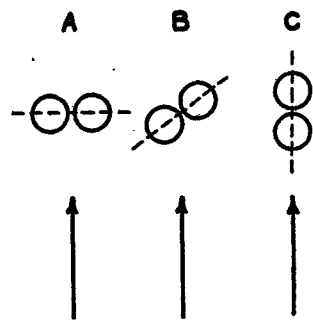


FIG. 2. DIAGRAM OF THE PLAN USED TO CONTROL THE RELATIVE SPATIAL ADVANTAGE OF TWO TEST-FOODS

with the arrangement shown in *C*, the food nearer to the approaching animal has a distinct advantage according to the principle of "first found, first eaten." If we start with test-foods placed in the standard position (*A*), and discover that the animal tends to eat consistently from the right or from the left tube, we should be able to counteract this tendency by rotating the axis of the food-containers to some position such as *B*, intermediate between *A* and *C*. For example, if we found that a rat consistently took the food at his right, we could withdraw the right and advance the left, as in *B*, thus changing the relative advantages of the two positions.

In practice the angular change was made only between trials, and it was kept constant for at least 2, 4, 6, 8, or more trials.

We tried a setting until we could satisfactorily observe its effect; and the standard procedure of interchanging the positions of the test-foods was held to throughout, regardless of the angular setting of the apparatus.

The results with this procedure were essentially the same as those with the sliding runway. On a number of occasions we found that when spatial factors were reduced to zero, food preferences *did* appear. We had the impression that the reduction or elimination of spatial dominance favored preferential discrimination, but we could not prove the point because we lacked adequate controls.

With several animals the procedure reversed the spatial pattern from right-eating to left-eating and *vice versa*, without forcing the rats to discriminate. This fact is theoretically important. It indicates that though our technique is adequate to balance out completely or even to reverse the spatial pattern of a rat, such elimination or reversal does not *force* the animal to make preferential discriminations between the test-foods. Although our plan favors the expression of preference, the rat cannot be coerced into making a choice. Sometimes he does and sometimes he does not reveal food preferences; the failure to express such preferences depends upon complex organic factors. But precise control of the relative position of test-foods does not and apparently cannot change the organic factors which mainly determine preferential behavior.

#### *General conclusions*

The observations described above lead to certain generalizations. (1) Within a group of eight rats marked individual differences were found in spatially-determined behavior between the extremes of complete right dominance and complete left dominance. (2) The factors of size and position of food may obscure the natural food preferences of an animal. (3) The techniques described above have proved successful in reducing, eliminating, and even reversing the apparent right-left dominance of a rat. (4) Equality of spatial advantage is the most favorable condition for the expression of food preference. But the attain-



ment of equal advantage in itself does not guarantee that preferential discriminations between foods will be made, because when two foods are presented with equal spatial advantage the expression of a preference or the failure to express a preference between them depends upon intra-organic factors.

In view of the above findings the writer believes that it is better methodologically to adhere to the standard conditions<sup>7</sup> of presentation in the food preference experiment than to vary them so as to counteract the individual's spatial bias.

## II. FOOD PREFERENCE EXPERIMENTS WITH A REVOLVING-CUP TECHNIQUE

Another attempt to control the space factor led to a rather elaborate experiment. The argument behind the experiment is this: two foods in the long run have precisely the same advantage in space and time, if placed in food-cups which are made to revolve slowly around a common center, and if the rat is given a free opportunity to eat from either. A measure of the relative time given to eating from each of the cups should serve as an index of preference. The revolving-cup technique forces an animal to pursue a moving food-cup in order to continue eating from it, and it gives repeated opportunities for discrimination between two test-foods.

To put the matter to an experimental test two food-cups were mounted on a rotating disk which was placed in the center of a large (19 x 19 inch), wire-mesh feeding table. The cups, made of brass (inside diameter  $1\frac{1}{2}$  inches, depth about  $1\frac{1}{4}$  inches), were mounted upon the disk so that their edges almost touched at the axis of rotation. The disk was rotated by an electric motor, the speed of which was reduced by a series of pulleys. The speed of rotation was varied between the extremes of 1 and 2.4 revolutions per minute; for a given test the speed was constant.

To the human eye the two cups were exactly alike in size, shape and color. They were distinguished by inconspicuous dabs of gray and white paint, and will be referred to as the "gray" and "white" food-cups.

<sup>7</sup> J. Comp. Psychol., 1932, 14, 297.

In an actual experiment the rat was placed upon the feeding table and timed from the moment he began to eat out of one cup.

The experimenter observed the rat closely and pressed a silent key when he ate from the "gray" cup and another when he ate from the "white." These keys connected the laboratory clock, located in a distant room, to two counters which counted time in seconds.

At the start the rat was allowed to eat for exactly 10 minutes. The counters showed the total time that the rat ate from the "gray" and "white" cups respectively. By subtraction from the ten minute period the total time that the rat did not eat was readily determined.

The subjects were six albino rats (males, no. 74, 75, 76; females, no. 80, 81, 82). The animals were about three months old at the start of the work, in the spring of 1932. The period of food deprivation, between 23 and 24 hours, was constant for all animals throughout the experiment.

#### *Control with wheat in both revolving cups*

In a series of control observations whole wheat powder was placed in both cups up to the same level. The rats were given a 10 minute eating test. Table 1 summarizes the results.

On the whole, the tendency to eat out of the "gray" cup is the same as that to eat out of the "white." There is no constant factor favoring either cup. There are, however, large chance variations, the magnitude of which appears in the table.

A partial explanation of these chance variations is the following. We observed that a rat would sometimes pursue for several revolutions the cup from which he started to eat, using it continuously without even sniffing at the other cup. This tendency to continue in a course of action once started, gave one cup an advantage for a certain time. But continued eating from one cup lowered its level of food so that food in the other cup had the compensatory advantage of being more accessible.

As we might expect, there was no consistent difference between the time given to eating from the "gray" and from the "white"

cups. If we total the eating times at *both* cups day by day for the group as a whole, we find these values: Day 1, 2195 seconds; Day 2, 2494 seconds; Day 3, 2610 seconds. The increase in the total eating time during a ten-minute period indicates a practice effect as the animals became increasingly accustomed to the apparatus.

*Comparison of wheat (W) and dry milk powder (D)<sup>a</sup> with the revolving-cup technique*

For fourteen consecutive days (April 18 to May 1, 1932) the six rats were given tests on the revolving-cup apparatus with

TABLE 1  
*Time in seconds that the rat ate from each of the revolving-cups*

RAT NUMBER	SEX	DAY 1 (4/11/32)		DAY 2 (4/13/32)		DAY 3 (4/15/32)		TOTALS	
		Gray	White	Gray	White	Gray	White	Gray	White
74	M	186	216	376	158	336	186	898	560
75	M	94	74	135	126	254	204	483	404
76	M	226	224	278	134	186	269	690	627
80	F	201	220	201	181	247	188	649	589
81	F	94	153	129	161	121	113	344	427
82	F	235	272	245	370	258	248	738	890
Totals.....		1036	1159	1364	1130	1402	1208	3802	3497

whole wheat powder (W) and dry milk (D). As in the control experiment, each animal was placed on the apparatus for 10 minutes, and the number of seconds given to the eating of the test-foods was counted. By subtraction, the total number of seconds during which a rat did not eat was determined.

Table 2 records the number of eating seconds given to D and to W by each rat on successive days of the experiment. It also shows the total time of the group given to the two test-foods, and the percentage of the total eating time given to eating D.

<sup>a</sup> We have consistently used the symbol D for dry milk powder to distinguish this food from liquid milk (M). D is really M minus water.

The figures in table 2 indicate that during the first three or four days of the experiment all rats spent more time eating W than D. This statement is true for each rat individually; it is very well marked in the total times of the group. The percentage of time given to D is lower on the first four days than for the rest of the experiment. Both absolutely and relatively there is a distinct gain during the early days of the experiment in the quantity of D ingested. The fact is shown graphically in figure 3.

TABLE 2

*Time in seconds that the rat ate each of two test-foods, wheat (W) and milk powder (D)*

DATE	RAT 74		RAT 75		RAT 76		RAT 80		RAT 81		RAT 82		TOTALS		PER CENT D OF TOTAL
	D	W	D	W	D	W	D	W	D	W	D	W	D	W	
4/18	10	357	112	151	167	178	86	347	52	243	232	235	659	1511	30.3
19	31	375	41	305	111	358	108	433	82	240	211	257	584	1968	22.9
20	15	326	215	218	178	351	282	281	204	228	237	282	1131	1686	40.1
21	0	438	120	292	221	224	265	397	291	172	252	251	1149	1774	39.3
22	512	353	167	206	295	249	247	326	360	165	211	308	1792	1607	52.7
23	130	290	170	250	273	289	286	289	427	119	267	288	1553	1525	50.4
24	75	376	226	230	317	266	284	285	521	82	316	268	1739	1507	53.5
25	247	243	160	379	288	333	313	277	456	126	355	236	1759	1594	52.4
26	71	486	266	241	307	275	292	300	524	62	322	230	1782	1594	52.8
27	74	584	275	314	208	274	281	250	482	91	352	236	1672	1749	48.9
28	201	383	259	311	302	290	355	259	447	126	307	267	1871	1636	61.9
29	158	413	243	253	273	317	264	326	527	62	317	269	1782	1640	52.1
30	163	405	260	286	260	330	299	300	418	158	273	246	1673	1725	49.2
5/1	192	386	290	250	312	269	319	260	374	165	288	274	1775	1604	52.5

As a possible explanation of the finding we wish to point out that prior to the experiment the rats had become habituated to eating W from *both* cups. This was in the three control tests described above. D was a *new* food to the animals; although a component of the daily ration, the animals had never tasted it in isolation. The rats continued eating W, to which they had become habituated, and as they became more and more accustomed to D, the amount of time given to this food increased without reduction of the time spent in eating W (fig. 3).

If we ignore the first four days on the ground that they constitute an habituation period and limit consideration to the remain-

ing ten days, we discover that the eating time for D is in general slightly greater than that for W. During the last ten days the total number of eating seconds was: for D, 17,398; for W, 16,181. The difference is relatively small and of low significance.

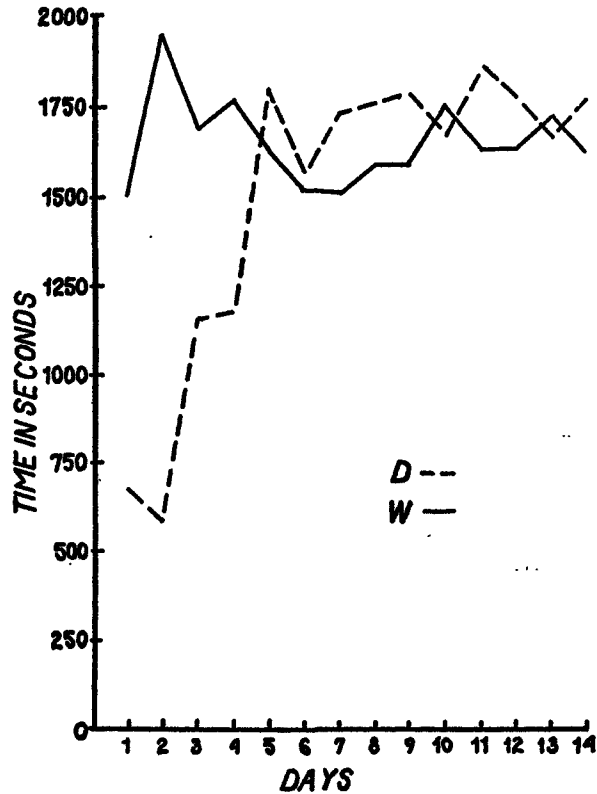


FIG. 3. TOTAL TIME GIVEN TO WHEAT AND DRY MILK BY A GROUP OF SIX RATS, WITH THE REVOLVING-CUP TECHNIQUE OF PRESENTATION

#### *Discussion*

It is very instructive to compare the results of the present experiment with those of the previous research in which we employed the standard preference technique.<sup>9</sup> We found in the former study that D and W were very close to each other on the

<sup>9</sup> J. Comp. Psychol., 1933, 15, 159-160.

scale of relative demand. In a group of ten rats, eight preferred W to D and two preferred D to W. The combined results for the total group led to the generalization that W was slightly preferred to D; moreover, there was a weak preferential trend in the direction of increasing preference for W.

At the start of the present work the results also indicated a preference of W to D, but the trend was towards equality of demand and after habituation D had a slight advantage over W. Thus the initial results with these test-foods were the same in both experiments but different after habituation.

The two experiments are not strictly comparable because of the great difference in the duration of eating time. In the food preference experiment each rat had a maximum eating time of 100 seconds per test (25 trials, each of 4 seconds); the total eating time for the three series with D and W was about 300 seconds per rat. This total is comparable in magnitude to the eating time on the *first day* of the present experiment.

The two studies, therefore, differ markedly in the total amount of time that the rat was allowed to eat on the apparatus. In the preference experiment with the standard technique this time was relatively brief; in the present investigation the eating time was much longer. We conclude that the results with a brief eating period as in the former preference experiment are different from those with a prolonged eating period.

In the former experiment the rats could not in the time allowed ingest enough food to affect appreciably their metabolic state, but in the present research, a considerable quantity of both test-foods was ingested. In the early preference work the rat was given the merest nibble of food, for a second or less.

Another difference between the two experiments is theoretically important. In the former method the animals were given opportunity to show their food preference in a *series* of trials. The present technique involved less necessity for discrimination. When a rat started to eat from one of the cups he sometimes followed it around continuously without actively discriminating between the foods.

In conclusion, the *initial* result with the revolving-cup technique agrees with that of the preference experiment—for most

animals W is preferred to D. But the *final* result is different—D is slightly preferred to W.

Two possible explanations of the difference are suggested: (1) as noted above, habituation to a test-food leads to the continued eating of it, so that a familiar food has an initial advantage over an unfamiliar one; (2) the quantity of food ingested is an important factor in determining the organic state of the subject, so the result after the animal has eaten a small quantity of food is different from that after a considerable quantity has been ingested.

In regard to the first explanation, that in terms of habituation, there can be no doubt that a preferential trend may be regarded as an habituation effect. An essential feature of the trend, however, is the *direction* in which it moves and that *direction* sometimes is found to reverse.

We found that the direction is regularly toward the preferred food. For example, when sugar was presented with flour, the trend was towards sugar, but when sugar was presented with milk, the trend was towards milk and away from sugar ( $M > S > F$ ). But sometimes when the initial demand for two foods was nearly equal the preference could not be determined until after the trend had had time to develop.

If habituation to sugar were the only factor determining choice, the trend would not be reversed when sugar was presented with a more highly demanded food. Habituation, therefore, is not in itself a sufficient explanation of preferential trends.

The second explanation, in terms of the quantity of food ingested, is a better one. Food demands and relative preferences depend upon the organic state. The organic state changes as an animal passes from hunger to satiety. A change in the animal's organic state with continued eating of a given food, we believe to be a more important factor than habituation in determining the result.

*Comparison of wheat (W) and sugar (S) with the revolving-cup technique*

On the days immediately following the above work the experiment was continued with wheat and cane sugar. Experimental

conditions were exactly the same as those described above except that sugar was abruptly substituted for dry milk.

The first three rows of figures in table 3 show the result. On the first day the animals were evenly divided between those preferring W and those preferring S, and the result for the group as a whole indicated an equality of demand for the two test-foods. But on the second and third days all animals showed a preference of W to S. This trend towards increasing demand for W is clearly revealed by the totals for the group as a whole.

TABLE 3

*Time in seconds that the rat ate each of two test-foods, wheat (W) and sugar (S)*

DATE	RAT 74		RAT 75		RAT 76		RAT 80		RAT 81		RAT 82		TOTALS		PER CENT S OF TOTAL
	S	W	S	W	S	W	S	W	S	W	S	W	S	W	
Eating period, ten minutes															
5/2	63	133	163	185	241	236	152	193	263	243	249	117	1131	1107	50.1
3	131	373	113	200	215	289	183	226	110	160	158	304	910	1552	39.9
4	110	332	185	293	240	323	147	351	136	182	177	287	995	1768	36.0
Eating period, five minutes															
5	57	229	101	153	108	164	99	165	119	43	128	76	612	830	42.4
6	101	172	116	118	87	181	92	136	116	51	79	138	591	796	42.6
7	149	105	129	218	138	136	116	145	153	17	24	162	709	733	47.5
Eating period, 100 seconds															
8	80	20	49	51	42	58	51	49	96	4	75	25	393	207	65.5
9	79	21	58	42	57	43	43	57	87	13	60	40	384	216	64.0
10	94	6	65	35	84	16	44	56	4	96	53	47	344	256	58.8

If the total number of seconds given to the eating of W on the first three days of the present series be compared with the total number of seconds given to W in the former series (table 2), it will be seen that the substitution of S for D brought a distinct drop in the total amount of time given to W. This decrease, however, showed a progressive change so that by the third day the total number of seconds given to W was comparable to that in the former series with W and D. But the percentage of total eating time given to S declined on the first three days, strongly suggesting a trend towards W and away from S.



This result is directly opposed to that of our former preference experiment. Comparing the two techniques it appears, as noted above, that in the former work the animals were forced to discriminate repeatedly between test-foods and were given the merest nibble to eat, whereas with the present revolving-cup technique there was less discrimination and vastly more time given to eating of the test-foods. With the present technique the rats had unlimited opportunity to eat freely of the test-foods for a ten-minute period. In view of the divergence in results we decided to observe what would happen if the total eating period were cut in half.

Accordingly for the next three days the experiment was terminated after an eating period of five minutes. Other conditions remained the same. Results with the five-minute eating period are presented in rows 4, 5, 6 of table 3.

For the group as a whole W was still "preferred" to S but there were marked individual differences. Rat 81, for example, consistently preferred S to W with the shorter eating period. Rat 82 preferred S to W on the first day of the period. On the last day rats 74, 76 (?), and 81 revealed a preference for S. The percentage of time given by the group to the eating of S indicated a slight, possibly not a significant, increased favoring of S. In other words, cutting the total eating time in half resulted in an apparent gain of S over W, but for the group as a whole W was still demanded more strongly than S.

We next decided to reduce the eating time still further. To make the results comparable with those of our previous work we limited the total eating time to 100 seconds.<sup>10</sup> With a slight change in the electrical wiring one of the counters was made to record the total number of seconds that a rat ate out of *both* ("gray" and "white") cups and the other the number of seconds that he ate out of the "gray" cup. By glancing at the marker from time to time it was possible to stop the experiment after exactly 100 eating seconds. Of course the total time required

<sup>10</sup> We previously used a series of 25 trials of 4 seconds each, making a total of 100 eating seconds, as noted above.

for an animal to eat 100 seconds varied from rat to rat and from day to day owing to variable pauses, so in this respect the timing differed from that of the previous days with a fixed duration of five or of ten minutes.

The record gave the number of seconds out of 100 devoted to eating of S, and by subtraction the number given to W. These values are recorded in the bottom rows of table 3.

From these last figures one can conclude that S is preferred to W. Considering the trend and the final result this is univocally the case with rats 74, 75, 76, and 82. With rat 80 the two foods are about fifty-fifty but with W slightly leading. Rat 81 preferred S to W on the first two days, but for an unknown reason reversed the preference on the last day. For the group as a whole the percentages of time given to S are distinctly higher than those with the longer eating periods; they are only slightly below the values obtained in the former preference experiment.<sup>11</sup> These percentages lead to a conclusion the same as that in the earlier preference work: S is preferred to W.

#### *Discussion*

The above experiment demonstrates clearly that the percentage of time given respectively to the eating of sugar and wheat varies with the duration of the observation period. With a ten minute period the total times indicate that wheat is "preferred" to sugar. With a five minute period wheat is still "preferred" to sugar but to a less degree, and there are wide individual differences among the animals. With an eating period of 100 seconds the figures indicate a preference of sugar to wheat, which result is in agreement with that of the former preference tests employing a brief eating period.

In other words, the relative preference between these two foods varies with the time that the rat has been allowed to eat them. With a brief eating period S is preferred to W but after a longer period of eating W is preferred to S. The change in organic state dependent upon the ingestion of the test-foods is, we assume,

<sup>11</sup> J. Comp. Psychol., 1933, 15, 155.

the factor which determines the mutation of preference.<sup>12</sup> Of course, we are dealing with *total* times and the actual mutation of preference is concealed by them, but it is none the less implied in our results.

If the above interpretation be applied to the results of the first series with D and W, these results can in a similar way be related to those of our original work. With a brief eating period W is slightly preferred to D, as we formerly found, but with prolonged eating D becomes slightly preferred to W.

All things considered the present study indicates that a brief period of eating (the merest nibble) gives results different from those with longer eating periods. In other words, the immediate preferential reaction is not the same as that after the animal has eaten a moderate quantity of the test-foods. The implication of the work is that the relative preference between two foods depends upon the degree to which an animal has approached satiation. The quantity of food ingested must therefore be considered in relation to the preferences at any time.

In summarizing the difference between the revolving-cup technique and the standard preference technique, we note: (1) The standard preference technique requires the animal to make repeated discriminations whereas the revolving-cup technique requires less frequent discriminations. With the revolving-cup technique the animal may continue eating a single food for a considerable time after a single discrimination. (2) The quantity of food ingested on the apparatus is much less with the standard preference technique than with the revolving-cup method. The latter method gives the animal an opportunity to eat indefinite quantities of the test-foods.

The difference between the quantity of food ingested on the apparatus, we believe, is primarily responsible for the divergence in results between the former preference experiment and the present one with revolving cups.

<sup>12</sup> We previously observed mutations of preference between butterfat and wheat. The reversal was sometimes quite sudden and we assumed that when an animal had become satiated on fat he turned to wheat. *J. Comp. Psychol.*, 1932, 14, 312; 1933, 15, 163.

### III. THE RATIO OF EATING TO NON-EATING TIME AS AN INDEX OF DEMAND FOR A SINGLE FOOD

From the preceding experiment it became evident that to predict and control relative food preferences we must understand the changing demand of an animal for a single food as he passes from hunger to satiety. Although the standard preference technique and the revolving-cup technique both indicate changes in *relative* preference as an animal continues to eat, neither method takes adequate account of the changing *absolute* demand for a single food.

The experiments described in sections III and IV, below, are planned to throw light upon the nature of changes in absolute demand as an animal passes from the organic state of hunger to satiety.

When a hungry animal is given an unlimited supply of food he eats steadily for a while; then as satiation approaches he is more and more readily distracted from eating, until finally he stops to sniff the air, to preen, to explore, at last deserting the food.

It is reasonable to expect that a record of the time spent in eating and non-eating as an animal passes from hunger to satiety will reveal the *gradual tapering off* of the time per minute that an animal spends in eating, and that the ratio between eating and non-eating time may serve as an index of the diminishing demand of the subject for a test-food.

Our experimental method for recording the time of eating and non-eating was simplicity itself. A rat was placed upon a wire-mesh feeding table, about 2 x 2 feet square, in the center of which was a dish of food. We used the standard diet which we have generally employed in work upon differential appetite.<sup>13</sup> An ample supply was present at all times in the dish of the apparatus.

The experimenter<sup>14</sup> sat quietly beside the feeding table, stopwatch in hand. As soon as the rat began to eat, the watch was started. The times at which eating ceased were recorded in a "non-eat" column of a mimeographed form, and the times that

<sup>13</sup> J. Comp. Psychol., 1933, 15, 150.

<sup>14</sup> The observations were made by Miss K. Johnston during December and January, 1933-4, under the writer's supervision.

eating commenced were recorded chronologically in an "eat" column. At exactly 30 minutes from the start the experiment was terminated.

Nine rats (no. 3, 7, 9, 11, males; 2, 4, 5, 8, 10, females), three months old at the start, were used as subjects. Each animal had been deprived of food for nearly 24 hours prior to the experiment; all observations upon a given rat were at the same time of day.

### *Results*

Graphic representations of the eating and non-eating times for a 30 minute period revealed considerable variation from time to time and from rat to rat. One record, typical of the others, is presented in figure 4.

The solid line indicates the duration of the rat's eating in seconds during successive minutes of the half-hour observation period; the blank spaces, times during which there was no eating. If a rat had his nose in the food or was seen to be chewing, this was counted as eating time; but if he left the food for exploration, regardless of whether or not there was food in his mouth, this was counted as non-eating time.

The graph gives a fair idea of the high degree of variability in the rat's feeding behavior. Sometimes an animal took the merest nibble of food; sometimes he continued eating steadily for several minutes.

Despite a careful and detailed study of the data we were unable to discover any fixed patterns in the ratio of eating to non-eating behavior. It is true in general that as satiation approaches, the pauses become more frequent and of longer duration, but during a given observation almost anything might happen.

When we total the results for the entire group the general decline in eating time with the onset of satiation is more apparent. Figure 5 presents graphically the average number of eating seconds, minute by minute, for the group as a whole. The curve is based upon 43 observations unequally distributed among nine rats. There were 3 to 7 records per animal.

The curve shows that for the first 20 to 25 minutes there was considerable variation about a mean of 49 eating seconds per minute. The first part of the curve gives no evidence of progressive or regressive changes. During the last 5 or more minutes, however, there was a marked decline to an average of 34 eating seconds per minute.

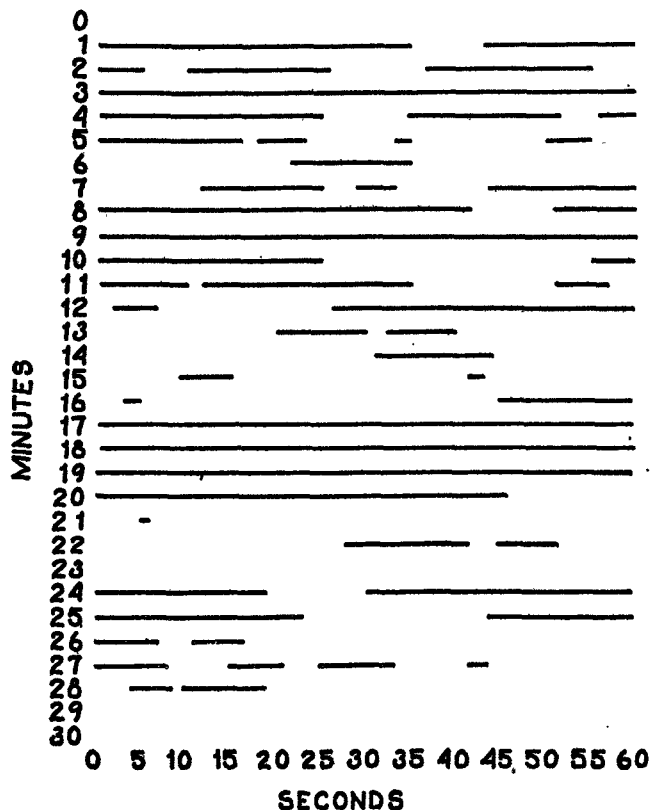


FIG. 4. DURATION OF EATING AND NON-EATING TIMES FOR A HALF-HOUR PERIOD; RECORD OF A SINGLE HUNGRY RAT HABITUATED TO THE APPARATUS

The abrupt decline seems to indicate a sudden onset of approaching satiation; but this impression of sudden change is probably not dependable in view of work to be described below.

Had the experiment been continued beyond the half-hour period, the decline would doubtless have reached the zero point.

It is of interest to note that the method gave no evidence of approaching satiation during the first 20–25 minutes. Some of the individual records, indeed, suggested a slight “warming-up” effect similar to that found in repetitive human work under some conditions.<sup>15</sup>

The main difficulty with *time* data is that they obscure changes in the *rate* of eating. Although the average duration of eating time per minute appears to be about constant for the first 20 or more minutes of observation, there were most certainly changes in the *rate* of eating. Fast and slow eating cannot be differentiated by a stop-watch. The time data tell no more about changes

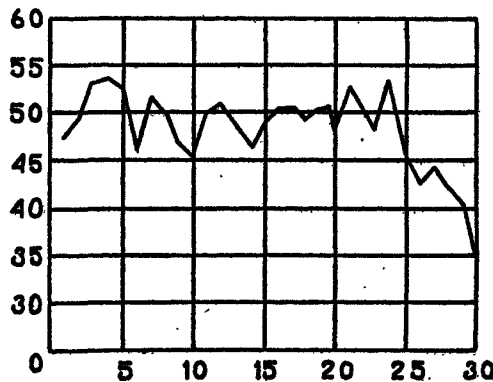


FIG. 5. AVERAGE NUMBER OF EATING SECONDS PER MINUTE FOR A HALF-HOUR PERIOD; THE SUBJECTS WERE A GROUP OF NINE RATS

in rate of eating than does the statement that an auto moved for fifteen minutes tell us about changes in its speed.

The present observation period was 1800 seconds. Of this time the animals, after preliminary habituation, spent between 1190 and 1753 seconds in eating.<sup>16</sup> With further habituation there was in general a slight increase in the total eating time per period.

<sup>15</sup> E. S. Robinson and W. T. Heron, The warming-up effect, *J. Exper. Psychol.*, 1924, 7, 81.

<sup>16</sup> This range is based upon 40 records; three were discarded because the animal went to sleep or otherwise indicated atypical sluggishness.

*Conclusion*

A study of eating and non-eating times as rats approach satiation, indicates that the ratio of eating to non-eating time is highly variable. Time records in themselves do not give an index of the variable *rate* of eating as an animal passes from hunger to satiety.

We believe that the ratio of eating to non-eating time is unsatisfactory as an index of changing demand for a single food, and turn, therefore, to a study of the *rate* of eating.

IV. RATE OF EATING AS AN INDEX OF DEMAND FOR A SINGLE  
FOOD

We have previously found that under carefully controlled conditions the relative food preferences of the white rat are uniform and statistically predictable. In several experiments we found that an initial preference disappeared or reversed with continued ingestion of the test-foods. In general our explanation has been that ingestion of a food modifies the metabolic state of the subject, and that food preferences are dependent upon that state at a given time.

Mutations of relative preference imply that the demand for one food is more quickly satisfied than that for another, and that to a certain extent there is a relative independence of action in the mechanisms regulating the separate demands for different foods.

If we could find some way to measure the absolute demand of an animal for a given food, and to measure the change in absolute demand under this or that condition, then conceivably we could predict the food preferences of an animal.

In the preceding experiment we studied the ratio of eating to non-eating time as an animal approached satiation, but we were unable to use the experimental data to measure changing demand. The times themselves do not and cannot give us *rates* of eating.

The difficulty with the *time* criterion is similar to that encountered with the criterion of *weight* of food ingested. A host of experiments upon the various aspects of nutrition have relied upon the weight of food eaten as the primary or exclusive measurement. These studies are concerned with growth, reproduc-



tion, health, and similar aspects of organic well-being. But for the psychologist who is concerned with the analysis of behavior, the total quantity of food ingested is an inadequate index of appetite. For one thing, the *weight of food eaten*, as we have previously noted,<sup>17</sup> does not afford a basis for distinguishing between true preferential discrimination and indiscriminate eating, nor does it reveal reversals in preference; further, the criterion of weight does not furnish at first hand the essential data for a behavioral analysis of differential appetite and aversion. The distinction between zero demand and aversion, for example, would be meaningless if the only information we possessed were that the animal failed to eat a particular food.

Again, the weight of food eaten is an inadequate criterion of appetite because an animal may become quickly satiated by a small amount of one highly-demanded food and then continue for some time eating considerable quantities of another food.

Suppose, for example, that a salt-starved animal were given unlimited quantities of salt and wheat. He would have a high demand for salt at the start of eating, but the salt demand would be soon satiated after the ingestion of a relatively small quantity of the substance. The wheat demand, on the contrary, would persist for a considerable time. The total weights of salt and wheat consumed during a three hour eating period would reveal nothing about the mutation of preference between salt and wheat.

It has occurred to us that if we could measure continuously the *rate* of eating a single food, the decrease in rate might be an index of the demand of an animal for the given food. This thought led to an experiment described below.<sup>18</sup>

To measure changes in the rate of eating, it is necessary to have a delicate apparatus which gives the weight of food ingested at

<sup>17</sup> J. Comp. Psychol., 1932, 14, 310.

<sup>18</sup> Our work upon the rate of eating is similar in plan and result to the investigations of Skinner and Bousfield: B. F. Skinner, On the conditions of elicitation of certain eating reflexes, Pro. Nat. Acad. Sc., 1930, 16, 433-8. W. A. Bousfield, Certain quantitative aspects of the food-behavior of cats, J. Gen. Psychol., 1933, 8, 446-54; Quantitative indices of the effects of fasting on eating-behavior, J. Genet. Psychol., 1935, 46, 476-9.

all times during the eating period. Such an apparatus is pictured in Plate I.

*Apparatus to measure the rate of eating.* The wire-mesh feeding table upon which a rat stands is shown turned upon its side at the left of the Plate I. The oval-shaped enclosure, fastened to the feeding table, is to limit the rat's opportunity for exploration. The enclosure, when in use, is covered with a wire-mesh cover to prevent the animal's escape. At one end of the enclosure the floor is cut away so that a rat can reach down into the food-cup; but the cup itself is so wide that the animal cannot touch the sides.

The food-cup (5 cm. in diameter and 3 cm. deep) is mounted upon an aluminum tray to catch food spilled by the rat during eating. The tray is attached to the arch of a chemical balance and suspended from a single point by a wire, as shown at the center of Plate I.

The cup unit is suspended at one end of a delicate lever-arm and counter-balanced by a weight (somewhat difficult to see in Plate I because it is exactly in front of an apparatus standard). The lever-arm is free to move up and down a few millimeters between two rubber-covered adjustable stops.

An essential part of the apparatus is a Jolly spring, attached to one end of the lever-arm and fastened below to a special clamp upon a meter stick. The purpose of this spring is to measure at any time the weight of food remaining in the cup.

The meter stick is fitted snugly into a vertical frame. The stick can be moved up and down, relaxing or stretching the Jolly spring. Friction between the stick and its frame can be regulated by means of a rubber-tipped clamp, which holds the stick in whatever position it may be placed. The action is smooth and silent. The position of the meter stick relative to the supporting frame can be read off in millimeters by reference to a fixed point on the upper support.

*Procedure.* In an actual experiment the cup is thoroughly cleaned and filled nearly to its top with the test-food. After this the meter stick is lowered until the lever-arm is seen to swing freely between the two rubber stops, indicating that the weight of the food has been exactly counter-balanced. The position of the meter stick is then read to the nearest millimeter and the value recorded as the initial setting of the apparatus.

The feeding table is next placed in position. Guide blocks screwed to the laboratory table assure a constancy of position throughout the

experiment. The rat is placed in the oval-shaped enclosure and the lid firmly fastened.

As soon as the rat starts to eat, a stop-watch is started. Continued eating throws the balance out of adjustment, owing to loss of food from the cup. The experimenter then raises the meter stick slowly and carefully to keep the food in the cup counter-balanced as accurately as possible. At the end of 60 seconds he reads the position of the stick and records this, and the time, upon a specially prepared data sheet. At the end of another 60 seconds the position of the meter stick is again read, and so on minute by minute throughout the half-hour period of observation.

The apparatus was calibrated by placing standard weights one at a time in the empty cup and adjusting the meter stick to counter-balance them. Results of these weighings were plotted; they showed a high degree of constancy and dependability of the apparatus. The graph was a straight line which turned out to be useful for converting readings in millimeters of scale into milligrams.

The apparatus measures decrease of weight of food in the pan as a rat continues eating; but since nearly all of the food which an animal spills is caught upon the tray or in the cup, the loss of weight in the food equals the gain in weight of the animal.

Because of the time consumed in making observations with the apparatus an automatic recording device is greatly to be desired. With automatic recording the period of observation could be extended indefinitely; the present half-hour period is too short. On page 580 we have suggested a modification of the apparatus which is intended for automatic recording.

### *Results*

Observations upon nine male rats, about three months old at the start of the series, were made during the spring and summer months of 1934.<sup>19</sup> The first work was in March, April and May with four rats; a second series in June, July and August employed five additional animals plus one of the original group.

The rats were given a constant quantity of standard diet daily, including 5 drops of cod liver oil, in addition to the test-foods

<sup>19</sup> The observations were made by Mrs. Mary Ritcher Rossiter, under the writer's supervision.

eaten upon the apparatus. The animals were weighed before being placed upon the apparatus. They were fed immediately after observation. Upon any given day the period of food deprivation at the start of an experiment varied between 23 and 24 hours.

Observations were made systematically upon three test-foods: (1) the standard diet, which we will call X (*mixture* of foods) to distinguish it from other foods; (2) sugar (S); (3) whole wheat powder (W).

All told we have curves for 187 half-hour observation periods—from the first series there were 73 and from the second, 114 curves. Two sample groups are presented in figures 6 and 7.

The curves are similar in their general characteristics to those published by Skinner and Bousfield. These curves show the gradual increase in volume of food ingested by a rat during a half-hour observation period. All curves in figures 6 and 7 are plotted from records of the same animal (male, no. 2).

The quantity of food ingested has been plotted in *cubic centimeters* instead of *grams*. The volume unit was employed, following the suggestion of a colleague that volume, rather than weight, is what counts in filling the mouth and the alimentary tract. The original data were in terms of grams. They were converted to volume units by means of coefficients. For each food we made ten independent weighings of a unit volume; we averaged the ten, and from the volume-weight ratio changed weight units into equivalent volumes.<sup>20</sup>

Our results indicate that it makes little difference which unit we employ. It is certainly not the filling of the mouth and alimentary tract alone which stops eating at satiation, because very different volumes of the test-foods are needed to produce satiation. The volume unit has a certain advantage in that all foods can be compared significantly in terms of equivalent bulk, regardless of their density, whereas weight in itself gives no indication of equivalent volumes.

The total quantity, expressed in grams, of a test-food eaten

<sup>20</sup> Our results were: for X, 1 gram = 1.99 cc.; for S, 1 gram = 1.15 cc.; for W, 1 gram = 1.85 cc.

during a half-hour period is shown in table 4. For all rats the standard diet is consumed in the greatest quantities, then wheat,

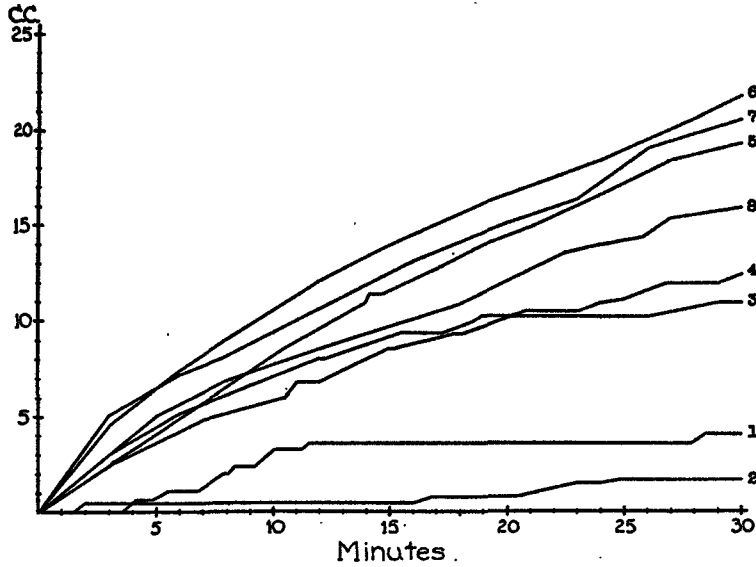


FIG. 6. CURVES SHOWING CHANGES IN THE RATE OF EATING DURING A HALF-HOUR PERIOD

Numbers at the right indicate order of the experiments, and show an habituation effect. The food is the standard diet used in the experiment.

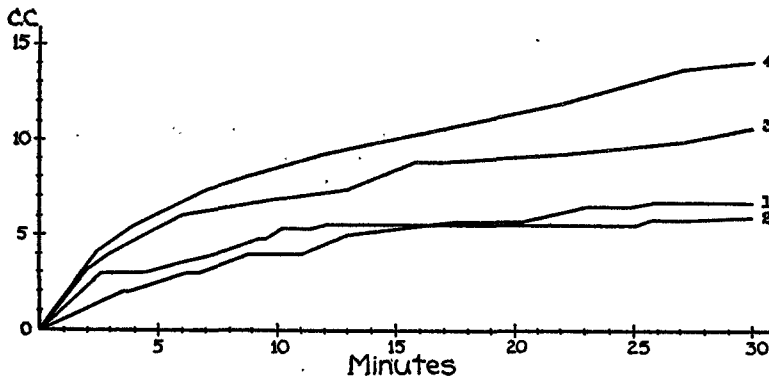


FIG. 7. CURVES SHOWING CHANGES IN THE RATE OF EATING SUGAR  
Numbers at right indicate order of the experiments.

then sugar. The picture is not significantly changed by converting grams into cubic centimeters.

Figures 6 and 7 illustrate the habituation effect. The numbers at the right record the order of observations. The curves represent results for one rat (no. 2).

The work was done in July and August, first upon the standard diet (fig. 6), then upon sugar (fig. 7). In the early stages of habituation (shown by the smaller numbers) there were long pauses during which the rat ate nothing; these pauses are indicated by straight lines parallel to the base. After more habituation to the apparatus the animals ate with increasing steadiness and continuity. The upper curves in both figures are typical of those from other animals after habituation. Habituation leads to the ingestion of greater quantities of food, as well as to steadier, more continuous eating (represented by the smoother curves).

TABLE 4  
*Average weight of food eaten, first experiment*

RAT	DIET			SUGAR			WHEAT		
	N	Average	A.D.	N	Average	A.D.	N	Average	A.D.
		<i>grams</i>			<i>grams</i>			<i>grams</i>	
3	5	8.1	1.2	11	3.9	1.2	4	5.5	1.4
7	4	2.7	0.5	8	1.6	0.9	4	2.3	0.3
9	5	3.9	0.8	9	2.5	0.7	4	3.4	0.5
11	5	6.8	0.6	10	3.2	1.8	4	3.5	0.7

From our curves several generalizations can be made. (1) All curves of approach to satiation are of the same general type; the animal eats rapidly at first, then slower and slower as he approaches the limit. (2) The limit of satiation varies with the degree of habituation to the apparatus. (3) The limit of satiation varies with the kind of food, being highest for the standard diet, intermediate for wheat, and lowest for sugar.

#### *Discussion*

A fair comparison can be made between the rate of eating the standard diet (X, curve 6, fig. 6) and sugar (S, curve 4, fig. 7). In terms of the absolute number of cubic centimeter ingested per minute, the rate of S consumption during the first five min-

utes is about the same as that for X. After five minutes the curves are clearly approaching different limits. At the end of 30 minutes the S curve has reached a cumulative total of about 14 cc., and the X curve a total of about 22 cc. If the experiment had been continued for several hours, S would undoubtedly have reached its satiation limit at a considerably lower level than X; for after a half-hour the S curve is near its upper limit and the X curve is still rising.

A basic fact revealed by our work is that an animal becomes satiated after eating different quantities of S, W, X, and presumably also of other test-foods. If a relatively small quantity of S as compared with X is needed to produce satiation, this small quantity can be ingested in a relatively brief time; the rat can become and actually does become satiated with S before X.

The same is true with S and W. The satiation limit for S is reached prior to that for W, judging from our curves.

Now we can readily assume that the quantity of a given food required to satiate an animal is an ideal limit or quantitative goal towards which behavior is moving with negative acceleration. If this quantity be considered as 100 per cent, we can specify at any time the proximity of satiation in terms of percentage of the final quantity already ingested, for example, as 50 or 75 per cent of satiation.

We are aware that the hypothetical quantitative goal varies with many factors; with the age and weight of the animal, with the previous diet, with the period of food deprivation prior to the experimental test, with environmental factors as temperature, humidity, distraction, illumination, with the opportunity to explore, with habituation to the apparatus, with obscure and complex organic factors which regulate food-demands in health and disease, with the social environment of the animal during the period of eating, and last but not least with the *kind of food* presented. The *kind of food* is obviously one among many factors which determine the quantity of food needed to satiate an animal under specified conditions. If all factors except the *kind of food* are held constant, the quantitative goals for different kinds of food can be experimentally determined.

The *rate of eating* is ordinarily expressed as the number of grams or cubic centimeters ingested per minute by the animal; but the *rate of approach to satiation* can best be expressed in terms of the percentage of a goal amount ingested per minute.

Incidentally, if we measure the rate of approach to satiation, rather than rate of eating, we may hold to measurements in grams instead of converting them into units of volume. This is true because the *relative* rate of eating is a ratio which is entirely independent of the unit in which the data are expressed.

The next point in our discussion touches upon the relation between the curves of approach to satiation, and changes in food preference.

It will be recalled that in the second experiment of this series, we found evidence for the view that S is preferred to W when the rat is given a brief preference test, but after prolonged eating of these foods W is preferred to S (page 559). Starting from this fact, we turn for a possible explanation to the curves of approach to satiation.

With habituated rats the approximate satiation limit for S is reached prior to that for W. If we estimate the theoretical limit of both S and W curves, and then arbitrarily take 25 per cent, 50 or 75 per cent of the ideal goal, S is found to reach the specified percentage consistently prior to W. In other words, the approach to satiation is more rapid for S than for W at all stages of appetitive satisfaction.

The hypothesis occurs to us that the *rate of approach to satiation*, rather than the absolute rate of eating, is the proper index of an animal's demand for a given food. During the first five minutes of eating the *absolute* rate of ingestion is about the same for S and W, but the *relative* rate—the rate of approach to the final quantity of food consumed at satiation—is higher for S than for W. This quicker approach to satiation, we suggest, indicates a higher initial demand for S than for W, which agrees with our finding that at the start of a feeding period S is preferred to W.

After the animal has eaten for approximately 5 minutes, however, the situation becomes different. Beyond 5 minutes the curve for S is commencing to level off, i.e., the rate of approach



to satiation is slowing down. This is true to a less extent for W.

One can understand that after a rat has become, let us say, 75 per cent satiated for S, the demand for S is low; but if at the same time he is only 60 per cent satiated for W, the demand for W (by assumption) will be higher. Because of the fact that the rat reaches a given degree of approach to satiation for S more quickly than for W, a prolonged free-choice feeding experiment should close with the rat preferring W to S, or perhaps without any preference between them.

The above argument admittedly rests upon insufficient evidence and our hypothesis is held tentatively. To go further than this, a new series of experiments upon food preference in relation to the degree of approach to satiation is required. Such an investigation, it is hoped, will be carried out before long.

Let us summarize the argument as follows: As a well-trained, hungry animal feeds upon a given food he eats at first rapidly, then slower and slower, until finally he stops entirely at the limit of satiation. Under constant habituation and other conditions the quantity of food needed to satiate an animal varies with the kind or quality of food; a quantitative goal or ideal limit can thus be experimentally determined for each kind of food. As a rat approaches this goal the relative changes in rate of eating constitute a goal gradient with negative acceleration. The rate of approach to the ideal goal rather than the absolute rate of eating is assumed to be an index of demand for a given food. It is proposed that this index of demand be experimentally tested in a study of mutations of food preference in relation to the degree of satiation for the test-foods.

#### V. NOTES AND DISCUSSION

##### *General hypothesis regarding the bodily mechanism of food demand and preference*

The chemical senses—taste and smell—are located at the entrance of the alimentary tract. One of their primary functions is to *test* foods before ingestion. This is especially true of taste. It is common-place that both man and animals smell and taste of foods before eating them, and that foods are somehow accepted

or rejected more or less eagerly on the basis of their sensory properties.

Closely related to this obvious fact is the experimental demonstration that the affective reactions to tastes and smells are quite stable.<sup>21</sup> We definitely like or dislike tastes and smells; we react positively or negatively to them, and apparently with more uniformity than to presentations in other sensory fields.

The next step in our argument is simply a recognition of the fact that an organism *needs* appreciable quantities of salt, sugar, fat, protein, vitamins, etc. in order to survive. All cells of the body *including the olfactory and gustatory cells* need these substances. Substances upon which the total metabolic state of the organism depends are circulated through the blood; the blood is the common medium of chemical exchange. The cells of the body take from the blood-stream substances needed for their survival and well-being.

We assume that if the whole body needs salt, the want of salt is present to some degree in the olfactory and gustatory cells as well as in all the others. If the body as a whole needs fat, this deficiency is present in the taste and smell cells. If the body as a whole needs carbohydrate, this deficiency is present in the taste and smell cells. And so on, for other needed substances. In a word, the chemical state of the olfactory and gustatory cells is here considered as giving a picture of the state of all the other cells, i.e., the state of the chemoreceptors is an index of the general chemical state of the organism.

Next we assume that individual gustatory and olfactory cells react positively or negatively to chemical stimulations; their response is a chemotropism, a direct assimilation or rejection of substances which come in contact with these cells. This positive or negative response varies in *degree* as well as in *direction*.

The cells of the two chemical senses are assumed to be minute chemical testing laboratories. These cells react positively or

<sup>21</sup> We found, for example, that children and adults were similar in their likes and dislikes for the smells of chemically stable organic substances; correlations between groups were above 0.90. E. H. Kniep, W. L. Morgan, and P. T. Young. The relation between age and affective reaction to odors. *Amer. J. Psychol.*, 1931, 43, 414.

negatively but their reaction depends primarily upon their own internal chemical state and the relation of the stimulus to this state. In other words, the response of these cells varies with the chemical condition of the organism. As that state changes following the continued ingestion of a particular food the response to a given stimulus changes.

When an animal eats a certain quantity of food the needed substances are absorbed by the blood, circulated through the body, taken up by all the cells, including the taste and smell cells. The process takes an appreciable time but eventually it changes the chemical state of the taste and smell cells themselves, which changed condition in turn regulates the accepting and rejecting responses of the cells.

Up to the present point our hypothesis about the chemical mechanism regulating the demand for food is simple and direct. It fits in with countless laboratory facts and, so far as I know, contradicts none. But another step is necessary to give a complete theory. These questions must be answered: How do the chemotropisms of the taste and smell cells initiate both positive and negative behavior? By what means are the nerve cells excited so as to lead to the gross responses of accepting and rejecting in varying degree of demand? How can varying demand, as shown in behavior, be explained?

I frankly do not know the answers to these questions at the present time. It may be that the degree of *neural* excitation is directly dependent upon the degree of electrochemical action in the receptor cells. But both inhibition and facilitation have to be brought somehow into the picture.

There are several arguments for our hypothesis. First, such an hypothesis is needed because ordinary explanations in terms of the hunger mechanisms are obviously inadequate. Second, a chemical theory offers a possible explanation for the known facts of specific appetite and aversion, relative food preferences, mutations of preference, etc., which otherwise have no explanation. Third, the facts of ingestion of food, differential demand for foods, preference, change of preference, etc. must from their very nature be explained on a chemical as well as on a neural basis.

Finally, the facts under consideration are *behavioral*; they relate to the dynamic adjustment between an organism and his food supply. A study of the internal bodily processes has not given, nor can it be expected to give, the primary *behavioral* facts about differential appetite. Obviously, behavioral study in this broad field of research, combined with carefully controlled chemical and nutritional procedures, holds the answer to the problem of the regulation of feeding behavior as expressed through varying demands and preferences.

At the present time there is not complete agreement about the relationship between bodily need and appetite. Harlow, Hausman, and others have affirmed that an animal chooses a diet according to his nutritional needs. In a recent study, however, Wilder has concluded that rats maintained upon a rachitic diet and permitted a brief choice period do not select on the basis of nutritional condition.<sup>22</sup> The whole problem should be examined thoroughly by the psychological techniques combined with adequate nutritional controls.

*Proposed apparatus for continuous measurement of the  
rate of eating*

The form of apparatus shown in Plate I is entirely satisfactory so far as precision is concerned. The only difficulty with it lies in the fact that its use is time-consuming. If the recording of the weight of food in a pan were done automatically, the observation could then be extended for several hours. Also by multiplying units a group of animals could be observed at once.

<sup>22</sup> Some of the more important recent references are: H. F. Harlow, Food preferences of the albino rat, *J. Genet. Psychol.*, 1932, 41, 430-438. M. F. Hausman, The behavior of albino rats in choosing foods and stimulants, *J. Comp. Psychol.*, 1932, 13, 279-307; *ibid.*, II. Differentiation between sugar and saccharin, *J. Comp. Psychol.*, 1933, 15, 419-428. A. H. Maslow, Appetites and hungers in animal motivation, *J. Comp. Psychol.*, 1935, 20, 75-83. C. E. Wilder, Selection of rachitic and antirachitic diets in the rat, *J. Comp. Psychol.*, 1937, 24, 547-577.

See also: W. F. Dove, A study of individuality in the nutritive instincts and of the causes and effects of variations in the selection of food, *The Amer. Naturalist*, 1935, 69, 469-544. M. F. Fritz, A classified bibliography on psychodietetics, *Psychol. Monog.* 1934, 46, no. 206; Pp. 53 (bibliog. on appetite p. 42-5).

In any comprehensive program upon the rate of approach to satiation, automatically-recording units should be employed with groups of animals. With this thought in mind we have sketched a tentative plan for an automatic unit. This is diagrammed in figure 8.

The food cup and catch pan (*F*) is given a point suspension. The lever is pivoted at a fulcrum (*P*) and made to swing freely between two rubber stops (one shown at *S*). An electric circuit is closed at the con-

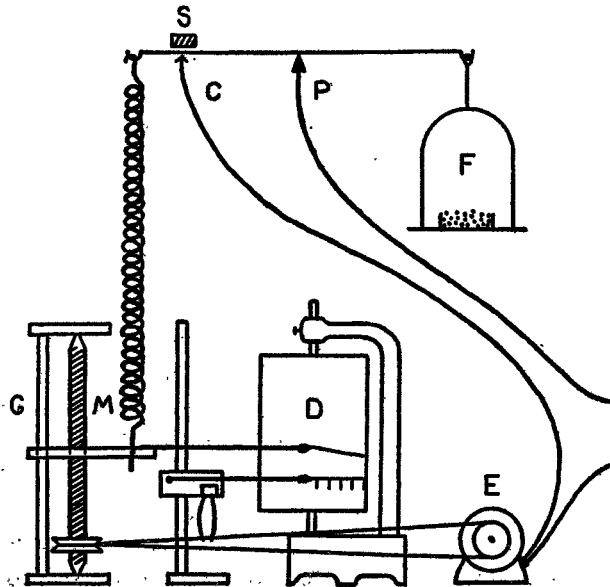


FIG. 8. PLAN OF APPARATUS FOR RECORDING AUTOMATICALLY THE RATE OF EATING

tact point (*C*) when the lever is down at the left, and the circuit is broken when the lever is up; the circuit is completed through the fulcrum point (*P*).

To one end of the lever is attached a Jolly spring of the appropriate sensitivity, exactly as in our hand-operated apparatus. The lower end of the spring is fastened to a support which can be raised or lowered by a micrometer screw (*M*) thus relaxing or tensing the spring. The support carries a marker for tracing upon a kymograph drum (*D*); the support and marker are held in alignment by a guide post (*G*).

An electric marker records time in minutes or some larger unit if desired.

An electric motor (*E*) is connected by a belt to the micrometer shaft. It would probably be desirable to have a small motor and to reduce the speed by a pulley system (not represented). Turning of the motor reduces the tension upon the spring and thus permits the lever arm to rise, breaking the contact at *C* and stopping the motor. When the contact is broken the motor remains at rest until the animal has eaten food from the pan sufficiently to let the lever swing back and close the contact at *C*.

It will be seen that the rate at which the marker rises on the drum (*D*) is a function of the rate at which food disappears from the cup (*F*). If the animal eats nothing, the record is a straight line; the faster he eats the faster the curve rises. Because food spilled by the rat falls through a wire floor into the pan or catch-tray, as in the apparatus shown in Plate I, the decrement in weight of the pan equals the increment in weight of the rat.

If the instrument has been calibrated carefully, the actual weight of the food in the pan can be read off in grams directly from the base line of the curve.

It is possible, and might be desirable, to substitute for the electric motor (*E*), a clock-work or phonograph motor, permanently attached to the micrometer screw. The stop and start of the clock-work could then be regulated by an electromagnet, or mechanically by a wire suspended from the lever arm.

#### *Criteria of food preference*

The general plan of the food-preference technique is to present the animal two foods in glass tubes of equal cross-section, the foods being leveled off at the top. On alternate trials their relative positions are interchanged.

In the early work we let the animal have a very brief period for sampling the foods—not over a second or two. As soon as we were sure of the preference exhibited, the foods were lowered out of the animal's reach. Our purpose was to observe the immediate preferential discrimination between the foods. A brief period of exposure permitted the rats to take only a nibble or two of one food. As soon as we had observed the initial response the

observation was terminated. Occasionally the rat would touch one food and then turn to the other, even within the brief period of exposure.

In later work we tried a standard four-second exposure period, determined by a metronome; and we standardized the series at 25 trials, a total of 100 eating seconds. The difficulty with this was that in four seconds the animal had ample time to turn back and forth from food to food and it was difficult to record the relative times given to the two foods. A system for recording, however, was worked out but in the end we had to estimate from a record whether the animal had spent more time eating one food or the other during the four seconds. We then assigned the preference for a particular trial to the food to which the rat gave most of his four-second eating period.

The work with a four-second period when combined with the results of the present study, however, leaves no doubt that the briefest practical exposure of the test-foods should be used in the preference technique. We believe that the exposure time should be kept at a minimum, and that the total preference test should be run off quickly. This plan forces the animal to make a prompt preferential discrimination if he makes any at all. The rat soon adjusts himself to this brief period and learns to take the preferred food.

We found that with a brief exposure period the rat sometimes takes consistently the food at his right or that at his left regardless of quality. This spatially determined pattern, as we have seen, indicates a failure to make preferential discrimination between the test-foods. Sometimes, however, the rat consistently takes one kind of food regardless of its relative position. This is the sign of genuine preference. Occasionally both of these principles are apparent at the same time, i.e., a rat consistently starts by eating the food, say, at his left; if this is milk, he continues eating it but if wheat, he turns to the milk, and so on trial after trial. The last pattern reveals both preference and spatial determination of behavior.<sup>23</sup>

<sup>23</sup> In the last pattern the animal learns to turn in a given direction to find the

We set up criteria for interpreting series of successive trials in terms of preference and no preference, for it became evident that a rat sometimes expressed his preference for a considerable period and sometimes he was indiscriminate.

To illustrate these criteria, suppose we consider any two foods, A and B. The following patterns for six successive trials indicate preference of A to B:

1	A	BA	AB
2	A	A	A
3	A	BA	AB
4	A	A	A
5	A	BA	AB
6	A	A	A

The first and second patterns are frequent; the third is rare. There are, of course, variations and combinations of these patterns.

The following patterns on six successive trials indicate no preference:

1	A	AB	AB
2	B	BA	AB
3	A	AB	AB
4	B	BA	AB
5	A	AB	AB
6	B	BA	AB

The patterns are in order of their frequency of occurrence. The third is rare. There are variations and combinations of these patterns. Especially to be noted is "alternate eating" or the "sampling reaction" which occurs with longer exposures of the test-foods; the rat eats alternately of the two foods and the pattern becomes ABABAB. . . . The interpretation of this behavior

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preferred food. Several times we observed the following behavior. In a series with flour (F) and dry milk (D) the rat continued eating D whenever it was on the left; but when F was on the left he turned to the right for D. This indicated a preference of D to F. Now on several occasions the rat by chance first met F when *this food was on the right*. After finding F the rat turned his head off into space at the right, as if searching there for D. Apparently a habit of finding F and turning to the right for D had been established.



is impossible unless there be accurate timing; it must be regarded as no preference.

The general principle in the preference as distinct from the no-preference patterns is that one of the foods is sampled during *every* trial, even though the alternative food is occasionally nibbled, smelled or tasted on some of the trials. In the no-preference patterns the series as a whole gives no indication of consistent discrimination in favor of either food, and so far as can be determined from the record both foods are equally demanded.

Underlying these patterns there appear to be at least three principles of behavior: (1) preference for one food over another; (2) spatial determination in which the position of a food rather than its quality determines eating; (3) sampling or alternate eating of foods. The third principle probably has some relation to gustatory discrimination and preference but in the record there is no clue for the interpretation of this pattern in terms of preference.

The above discussion makes it clear that preference cannot be determined by a single brief trial. At least two consecutive trials are needed with the positions of the foods interchanged. The double-test rather than the single trial is the true unit in the food-preference experiment. For this reason a test series should have an even number of trials, not an odd (as in one of our former series of 25 trials). The double-test unit can be rated as showing preference for A or for B or no preference.

Actually the patterns described above show variation within a series. One pattern will give way to another as the series progresses. But when the animal's behavior is viewed time-wise one can readily interpret the series in terms of preference and of no preference.

## VI. SUMMARY

The present report describes a series of experiments upon food demands and preferences of the white rat. The report is divided into five parts, each of which is summarized below.

I. *Spatial factors in the feeding behavior of rats.* Eight rats

showed marked individual differences in spatial behavior between the extremes of right and left dominance. The tendency of an animal to eat the test-food in a given position, right or left, frequently appears instead of preferential discrimination. Two attempts were made to control the factor of position. (1) The path of approach to the test-foods was moved bit by bit to the right or left. (2) The angular position of the pair of food-containers in relation to the line of approach was varied so as to advance one and withdraw the other.

Both methods gave the same result. It was possible to reduce, eliminate and even reverse the tendency of an animal to eat the food in a given right or left position. When the spatial advantage of both foods was the same, the conditions were most favorable for discovering the rat's food preferences. The animal could not, however, be forced into making a choice. Preference is assumed to depend upon organic factors rather than upon the environmental arrangement of test-foods.

II. *Food preference experiments with a revolving-cup technique.* The experiment was tried of having two food-cups revolve slowly about a common central axis while the rat had unlimited opportunity to eat from them. The time given to each food was recorded by electric counters. Three series were run: (1) a control with wheat powder in both cups; (2) a test with wheat powder and dry milk; (3) a test with wheat powder and cane sugar.

Results suggest that habituation to eating wheat may be a factor in the continued eating of this food when it is presented with another, e.g., dry milk. Both test-series, considered in relation to results gained by the standard preference technique, show that a brief eating test may give a result different from that of a prolonged eating test. With a brief test sugar is preferred to wheat, but with a ten minute eating period wheat is "preferred" to sugar.

To explain this divergence of results it is assumed that as an animal approaches satiation continued eating of a food brings a change of metabolic state, and that this change determines the relative demand for the test-foods.

In comparing the revolving-cup technique with the standard

preference procedure it is noted: (1) that the preference technique requires the rat to make repeated discriminations; (2) that the quantity of food ingested in the preference experiment is much less than that with the revolving-cup technique.

III. *The ratio of eating to non-eating time as an index of demand for a single food.* Individual rats were timed with a stop-watch for half an hour of feeding; a record was made of eating and non-eating time. For the individual rat much variability was found in the eating/non-eating ratio. For the group of 9 rats as a whole the average was about 49 eating seconds per minute for the first 20-25 minutes with a decline to 34 eating seconds at the end of a half hour. As satiation approaches the eating/non-eating ratio is so variable that it is of little value as an index of demand for a single food; but the main difficulty with the index is that it fails to reveal changes in the *rate* of eating.

IV. *Rate of eating as an index of demand for a single food.* To measure the rate of eating, a lever arm and Jolly spring were used for determining the weight of food in the pan every minute during a 30 minute period. Since food spilled by the rat was caught on the pan, the curve of decrement in weight of the test-food can be exhibited as a curve of increment in weight of the rat. With 9 rats as subjects, a total of 187 curves was obtained for wheat, sugar, and a standard diet. These curves confirm those of Skinner and Bousfield.

The quantity of food needed to satiate a rat varies with the kind of food, being highest for the diet, next for wheat, and lowest for sugar. The quantity of food ingested during any given experiment shows an increase with habituation to the feeding conditions.

It is suggested that the *rate of approach to satiation* rather than the absolute rate of eating is the proper index of demand for a single food. According to this criterion sugar is more demanded than wheat or diet at the first presentation, but after 10 or more minutes of eating, sugar is less demanded than the other foods. This criterion of demand enables us to explain why food preferences reverse as an animal approaches the ideal limit of satiation.

V. *Notes and discussion.* In the final section three brief con-

tributions are made. (1) A general hypothesis is presented regarding the chemical and biological nature of the mechanisms regulating food demand and relative preference. (2) An apparatus is described for continuous and automatic recording of the rate of eating. (3) The criteria of food preference are reviewed and discussed in the light of available results.

The whole series of studies shows the need for further work upon the relation of food preferences to the demand for single foods, and especially upon the problem of changing demand with the approach to satiation in relation to changing preferences.

PLATE I

APPARATUS TO MEASURE THE RATE OF EATING

