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CHRONIC EXTINCTION AND RESTORATION OF CONDITIONED REFLEXES.

I. EXTINCTION AGAINST THE EXCITATORY BACKGROUND.

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1. INTRODUCTION

The present paper is devoted to the detailed study of processes which occur in the course of elaboration of inhibitory conditioned reflexes and their transformation back into active conditioned reflexes.

It is well known that the investigations of internal inhibition have been chiefly concerned either with acute inhibition, which constituted the extinction of conditioned reflexes, or with the chronic inhibition, which constituted differentiation in the broadest sense of the word.

The production of an acute extinction is inappropriate for our purpose because it involves changes in the excitability of the unconditioned centre, and it strongly disturbs the normal course of the conditioned reflex experiment. On the other hand, the elaboration of a differential inhibition by the non-reinforcement of a stimulus similar to the conditioned stimulus, which is reinforced, has the defect of depending on the degree of similarity of both the stimuli and therefore its course cannot be considered as „standard".

For the above reasons we decided to study such a form of internal inhibition as would not possess any of the defects specified. This form is the chronic extinction of a conditioned reflex. For, firstly, when we apply an extinguished stimulus once or twice amongst positive stimuli during the experimental session, we do not disturb the normal course of the experiment and we can examine accurately the gradual process of the transformation of this stimulus into the inhibitory stimulus. Secondly, the course of the elaboration of an inhibitory reflex is in this case not disturbed by the circumstance that the stimulus more or less similar to the inhibitory stimulus is reinforced. Thirdly, the starting point of the elaboration of the inhibitory reflex is strictly determined: we know both strength of the conditioned reflex to be extinguished and the degree of its fixation. The same applies to the reverse process, i. e. the restoration of the chronically extinguished stimulus by its application with the reinforcement among other stimuli.

The most important results of this paper can be summarised as follows: while the chronic extinction is a very slow process and its rate depends on the character of the stimulus and the degree of its fixation, the restoration of the inhibited reflex is a rapid process, which occurs almost from day to day and is practically the same for all stimuli.

In addition to these experiments the repeated extinction and restoration of one and the same stimulus was tested. Interesting results which were here obtained require further examination.

2. METHOD

In our experiments, the classic method used in Pavlov's school for the investigation of alimentary conditioned reflexes was applied (Podkopaiev 1936).

In order to make the results more exact, we introduced a modification, which consisted in replacing air by water in the system of tubes leading from the salivary fistula to the manometer (Kozak 1950). In all this system only lead tubes and hard rubber tubes were used in order to minimise in the results falsification caused by the movements of the animal's head.

Dogs used in these experiments were fed once a day between 4 and 5 p. m. The experiments were carried out every day (except holidays) between 8 and 11 a. m. Experimental sessions lasted about 20-40 minutes.

As conditioned stimuli, various auditory and visual stimuli were applied. The order of the application of stimuli was not constant, the intervals between trials were usually 4 — 7 minutes. The duration of the isolated period of conditioned stimuli was in all experiments (except in those at the beginning of the training) 20 seconds. The food was given in small bowls presented to the dog by means of a mechanical device. The food consisted of dried minced bread, moistened in regular, constant quantities with broth.

3. RESULTS

Two dogs (mongrels) were used in the experiments; their weight was from 10 — 12 kg, their age — 2 — 3 years. One of them„„Bobik" was very lively and voracious; his conditioned reflexes were considerable and regular. The other dog, „Cygan", was less excitable, his conditioned reflexes were not so regular and tended to diminish towards the end of the experiment.

In both these dogs, conditioned reflexes to the following stimuli were established: a beat of a metronome, the ringing of a bell (strong stimuli), the sound of a buzzer, bubbling in water, a whistle (weaker stimuli), and an electric lamp (the weakest stimulus).

A. THE COURSE OF CHRONIC EXTINCTION OF ACTIVE CONDITIONED REFLEXES

The chronic extinction of various stimuli was carried out on „Bobik". It was conducted always in more or less the same standard way. In every series of experiments only one stimulus was subjected, by applying it without reinforcement among other stimuli usually on the third or fourth place, to extinction. At the beginning of the first series, the stimulus subjected to extinction was applied twice during each experiment; afterwards we found it more practical to apply it only once. To illustrate the course of an experiment we adduce one of our protocols (Table I).

After each series with extinction another series with the restoration of the extinct stimulus followed, and only when the restoration was fully accomplished a new series with the extinction was conducted.

Table I.

A typical course of experiment with chronic extinction.

„*Bobik*" 12 th March 1949, Nr 228.
(The seventh day of extinction of lamp).

Nr of trial	Time in min.	Conditional stimulus	Salivary conditioned reaction			Rein-forcement	Unconditioned reaction	
			first 10 sec.	second 10 sec.	total		first 10 sec.	subsequent 20 sec.
1	1	Bell	14	21	35	+	37	73
2	6	Metronome	18	20	38	+	42	73
3	11	Lamp	14	8	22	—	4-6-5-1 (every 10 sec)	
4	16	Metronome	12	18	30	+	35	75
5	20	Bell	18	25	43	+	40	72

The following series of extinctions were performed („Bobik"):

13th April 1948 — 3rd May 1948, the first extinction of the metronome,
7th September 1948 — 5th October 1948, the second extinction of the metronome,
23rd October 1948 — 18th January 1949, the third extinction of the metronome,
3rd March 1949 — 11th March 1949, the extinction of the lamp (a weak stimulus firmly established),
7th April 1949 — 11th May 1949, the extinction of the whistle (a fresh strong stimulus),
13th June 1949 — 6th October 1949, the extinction of the bell (a strong stimulus firmly established).

The course of extinction of various stimuli is represented in figs 1 and 2. These graphs were constructed in the following way: each curve represents the course of extinction of the conditioned reflex to a particular stimulus. From every three successive experiments the mean magnitude of the conditioned reflex to the stimulus, which was being extinguished, and the mean value of the conditioned reflex to a strong positive conditioned stimulus were taken. (As a standard strong stimulus we took the bell, and in experiments with the extinction of the bell — the metronome). Then the first of these values was taken as a percentage of the second. Since the magnitude of conditioned responses during the first 10 seconds of the isolated period of a conditioned stimulus fluctuated in accordance with the

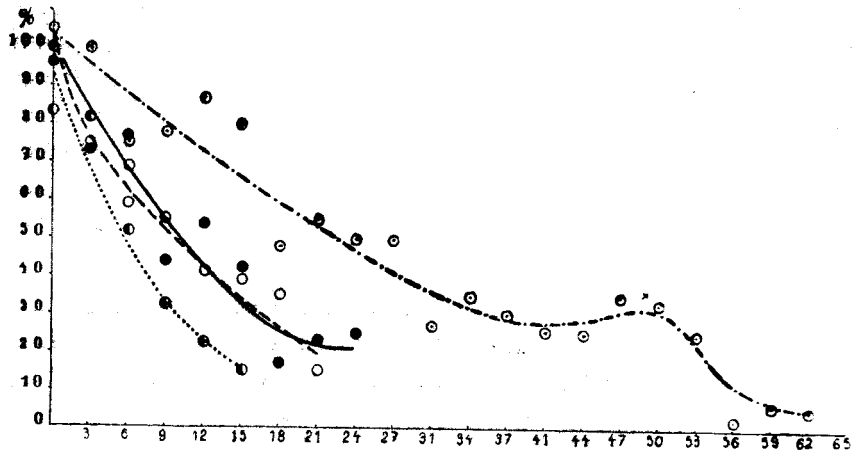

Fig. 1. Chronic extinction of conditioned reflexes to metronome, whistle, bell and lamp in „Bobik".

Abscissae: successive days of experiments.

Ordinates: magnitude of reflexes as a percentage of standard positive reflex.

———————— metronome
— — — — — — — — whistle
— · — · — · — · — bell
. . . . . lamp
x, reinforcement given in error.

length of the intervals and with the spontaneous salivation just before the trials and so on, we used for the construction of the curves only the values of the responses to the second 10 seconds of the isolated period of a conditioned stimulus; these values were much more stable. Yet it should be mentioned that the curves constructed on the basis of all the values of the conditioned reflexes (during 20 seconds) did not differ notably from the curves represented here. The values of the standard conditioned reflex to the first stimulus in an experiment, and to a stimulus applied just after an inhibitory stimulus were not taken into account, as they were irregular and somewhat diminished.

As is seen from fig. 1 there are great differences in the rate of chronic extinction of various stimuli: 1° the extinction of firmly established conditioned stimuli is slower than that of fresh stimuli; 2° so called strong stimuli are extinguished more slowly than weak stimuli.

Ad 1°: The metronome in its first extinction can be considered as a relatively fresh stimulus since it was trained only in the course of 74 trials. Its extinction to the value of 20% of the normal value occured in 23 trials. Similarly the whistle, which was trained as a conditioned stimulus in the course of 16 trials, was extinguished to the value of 20% in 20 trials. On the other hand, the bell, a stimulus of the same strength but much more firmly established (667 trials), was extinguished to the value of 20% in 42 trials.

Ad. 2°: If we compare the extinction of the lamp which is a weak conditioned stimulus with the extinction of the bell which is a strong stimulus, the great difference between them is easily seen although the „age" of the respective reflexes was about the same. These data are represented in table II.

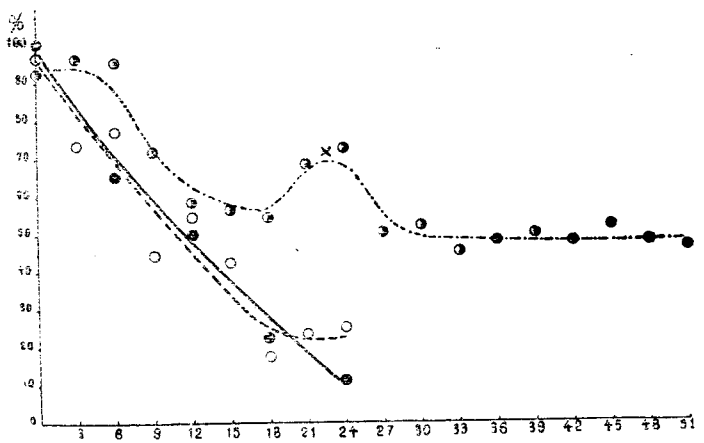

Fig. 2. Multiple chronic extinction of conditioned reflex to metronome in „Bobik".

Abscissae and ordinates as in fig. 1.

——————— the first extinction

— — — — — — — — the second extinction

— · — · — · — · — the third extinction.

x, as in fig. 1.

The process of the multiple extinction of the metronome deserves special consideration. As is seen from fig. 2, in the first extinction the reflex to the metronome was extinct to 20% after 23 trials.

Afterwards this stimulus was reinforced only in the course of 10 trials and then it was re-extinguished.*) This time the extinction to 20% occurred also in 23 trials. After the second extinction, the stimulus was again applied with reinforcement 10 times and then re-extinguished again. This time it was impossible in spite of 60 trials to extinguish the metronome below the value of 50% of the value of the bell.

Table II.

The number of trial in which a conditioned stimulus was extinguished to 20% of a standard value.

	Metronome	Lamp	Bell	Whistle
The number of reinforced trials before extinction	74	495	667	16
The number of unreinforced trials till 20% of a standard value achieved	23	14	42	20

How much a single reinforcement of an extinguished stimulus can disturb the course of extinction is seen from the „hump" in the third curve of extinction (x). This hump was caused by one reinforcement given in error. Its effects lasted for five days and only then did the values of the reflex return to the previous level (50% of the bell). A similar hump caused in the same way is seen in fig. 1. (x).

B. THE RESTORATION OF THE EXTINGUISHED CONDITIONED REFLEXES

When the inhibitory conditioned reflex to a given stimulus was established, we changed the experimental procedure in such a way that the inhibitory stimulus was again reinforced by the presentation of food. The first restoration of the conditioned reflex to the metronome both in „Cygan" and „Bobik" was conducted rather „acutely", i. e. we applied the metronome with reinforcement several times during an experimental session. In the following series it ap-

*) It is worth mentioning that after 10 reinforcements there was a 53 days interval in experiments. After this interval the reflex to the metronome was fully preserved.

peared that it is more correct to employ „chronic" restoration of the extinct reflex (by applying the restored stimulus once per session), i. e. to act exactly in the same way as in the case of chronic extinction.

Appended are protocols of the experiments on „Bobik" and „Cygan", representing „acute" restoration of the conditioned reflex to the metronome (Table III and IV).

Table III.

The course of acute restoration of metronome.
"Cygan," **6 th July 1948, Nr. 120.**

Nr. of trials	Time in min.	Conditioned stimulus	Salivary conditioned reaction			Reinforcement	Unconditioned reaction	
			first 10 sec	second 10 sec	total		first 10 sec	subsequent 20 sec
1	3	Lamp	5	9	14	+	33	71
2	8	Bell	13	15	28	+	41	78
3	13	Metronome	1	4	5	+	33	80
4	18	Metronome	3	7	10	+	33	80
5	24	Metronome	3	11	14	+	40	79
6	29	Metronome	1	9	10	+	38	78
7	34	Metronome	1	3	4	+	40	73
8	39	Bell	9	18	27	+	44	75

"Cygan," **8 th July 1948, Nr. 122.**

1	2	Lamp	8	10	18	+	33	77
2	7	Bell	19	27	46	+	40	78
3	12	Metronome	15	22	37	+	47	71
4	17	Metronome	11	14	25	+	44	83
5	22	Metronome	7	21	28	+	47	79
6	27	Metronome	5	11	16	+	50	79
7	32	Metronome	9	21	30	+	45	83
8	36	Bell	11	25	36	+	41	84

Consider first the protocols concerning „Cygan". We see that in the first experiment with the reinforcement of the metronome (Nr 120) the reflex to this stimulus behaves in a peculiar way: at the beginning, it increases (5 — 10 — 14) and achieves a half value of the reflex to the bell, then it falls rapidly (14 — 10 — 4). That this fall concerns only the stimulus just restored is seen from the fact that to apply the bell after it gives a normal effect. In the experiment Nr 121, the metronome was not applied, while in the experi-

ment Nr 122 this stimulus produced at once very great effect (37), fluctuating in successive trials (25 — 28 — 16 — 30)

Table IV.

The course of acute restoration of metronome

„Bobik", 13 th July 1948, Nr 105.

Nr of trial	Time in min	Conditioned stimulus	Salivary conditioned reaction			Rein-forcement	Unconditioned reaction	
			first 10 sec.	second 10 sec.	total		first 10 sec,	Subsequent 20 sec.
	1	Lamp	10	12	22	+	34	64
	6	Bell	21	26	47	+	39	72
	10	Lamp	11	16	27	+	39	74
4	14	Metronome	4	1	5	+	34	76
5	18	Metronome	5	10	15	+	38	75
6	22	Metronome	7	7	14	+	39	78
7	27	Metronome	8	11	19	+	38	79
8	32	Bell	16	17	34	+	38	69

„Bobik", 14 th July 1948, Nr 106.

1	1	Lamp	15	16	31	+	39	75
2	6	Bell	21	25	46	+	40	76
3	11	Lamp	15	22	37	+	40	78
4	15	Metronome	15	24	39	+	40	79
5	19	Metronome	16	22	38	+	40	81
6	23	Bell	16	24	40	+	40	80
7	28	Metronome	10	20	30	+	41	80
8	33	Lamp	10	12	22	+	38	82

The course of the restoration of the reflex to the metronome in „Bobik" was very similar. In the first day of restoration the reflex increases and stops on the value of about 50% of the bell (5 — 15 — 14 — 19) without subsequent fall as in the case of „Cygan". The next day, the reflex to the metronome is at once fully restored being almost equal to the reflex to the bell.

So we see that the acute restoration of a conditioned reflex is interrupted by another process, opposite to that of restoration, which prevents the reflex from appearing to its full extent. The analysis of this second process will be given later; here we shall note that it was its existance which urged us to apply only chronic restoration in the following series of experiments.

To conclude the considerations of the protocols adduced, it is worth mentioning that in both dogs the unconditioned reflex produced by the first reinforcement of the metronome was slightly diminished.

Table V.

The restoration of extinguished conditioned reflexes in *„Bobik".* The value of the second 10 sec. of the stimulus as a percentage of standard stimulus.

Successive days of exper.	Metronome (second restoration)	Lamp	Whistle	Bell	Means
0	20	23	17	0	
1	58	63	47	65	58
2	83	110	60	90	86
3	88	96	80	90	89
4	90	91	90	100	93
5	96	100	80	68	86
6	94	85	91	130	100
7	95	100	91	110	99
8	95		100		98

The results of the chronic restoration of reflex in „Bobik" are represented in Table V. As this table shows, in all cases of the restoration, the conditioned reflex grew rapidly from day to day. While immediately before restoration the extinct reflex amounted on the average to 20% of the reflex to a strong stimulus (with the exception of the metronome extinguished for the third time which was inhibited only to 46%), a single reinforcement was sufficient to increase the reflex to 58%, and the second reinforcement — to 86%.

In the subsequent few days the reflex reached its normal value. And so the process of restoration of a conditioned reflex occurs much more rapidly than the process of its suppression; it seems as if the dog throughout the period of extinction were expecting the moment when the stimulus would be reinforced, and reacted to this change immediately.

C. THE INFLUENCE OF THE ALIMENTARY EXCITABILITY ON THE MAGNITUDE OF THE EXTINGUISHED AND RESTORED CONDITIONED REFLEXES

In a few experiments we examined the magnitude of conditioned reflexes in the course of extinction and restoration against the background of the diminished alimentary excitability, which was caused by feeding the animal before the experiment.

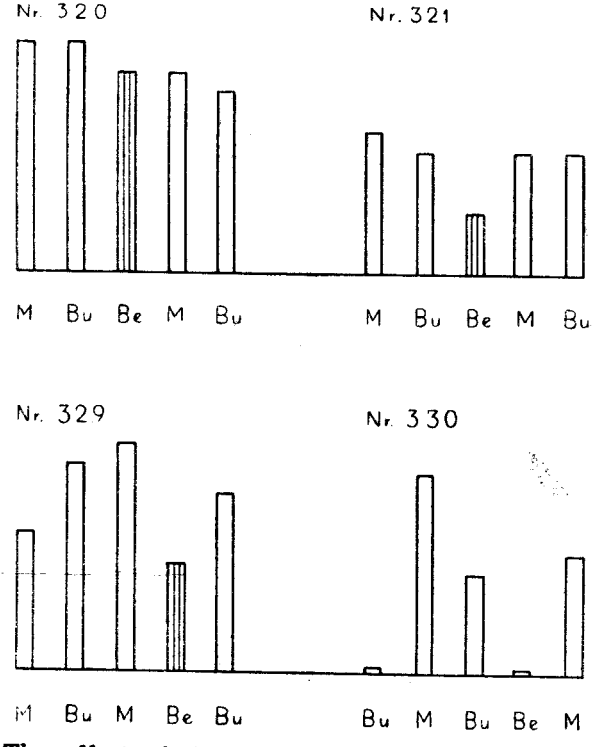

Fig. 3. The effect of diminished alimentary excitability upon the magnitude of the reflex in the course of extinction (M — metronome, Bu — bubbling, Be — bell).

As examples, let us cite experiments in which the effect of the diminished excitability on the reflex in the course of extinction was examined.

Appended are two successive protocols from the series of experiments in which the reflex to the bell was being extinguished (fig. 3). In the experiment Nr 320 (21st day of extinction) the reflex to the bell was still equal to other reflexes, while in the next experiment, when the alimentary excitability was diminished, it amounted only to a half of their value. Similarly, in the experiment Nr 329 (30th day of extinction) the reflex to the bell still amounted to more than a half of the reflex to the metronome, while in the experiment Nr 330, against the background of the diminished alimentary excitability, the bell had a nil effect. It can be said that the diminution in alimentary excitability makes clear the differences between various states of the stimuli, which differences are not visible in „normal" condition.

Unfortunately, the problem of the effect of the diminished excitability upon conditioned reflexes in their transitory stages (i. e. in earlier periods of extinction or just after restoration) was not worked out satisfactorily in the present experiments. Therefore we are not able to say at what stage in the course of extinction the phenomenon just described appears, and at what stage in the course of restoration it vanishes. In any case those few experiments which we have performed seem to indicate that in the course of transformation of excitatory conditioned reflexes into inhibitory, and vice versa, there are stages in which, in spite of apparent lack of differences between the transformed reflexes and „normal" reflexes, these differences can be evidenced by the aid of lowering alimentary excitability.

4. DISCUSSION

Some questions raised in this paper require more detailed consideration. The first of these questions is the clearly expressed dissymmetry between the process of chronic extinction of a conditioned reflex and the process of its chronic restoration. In the best case, the chronic extinction to the level of 20% of the normal value lasts 14 days (lamp), while *restitutio ad integrum* of the conditioned reflex with its re-reinforcement lasts in all cases 3 — 4 days.

The problem arises as to what may be the cause of this dissymmetry. First, it is clear that it does not depend (or it depends only to an insignificant degree) on the relation between the duration of the excitatory and inhibitory training of given stimulus. The best proof of this is the extinction of the whistle. This stimulus was trained as an active conditioned stimulus for only 8 days, while as an inhibitory stimulus it was trained for 24 days, and nevertheless, as soon as this stimulus was again reinforced, its return to the active state was almost instantaneous. And so the cause of the phenomenon in question must be sought elsewhere.

The following factors can here be taken into account: 1°. The strength of the reinforcing unconditioned stimulus. It is commonly accepted that the stronger the reinforcing stimulus, the easier and more rapid is the process of elaboration and the slower the extinction of the conditioned reflex. In our experiments, the reinforcing stimulus was undoubtedly very strong. The dog came to our experiments after a day's starvation, his alimentary excitability was very high, and he received very tasty and attractive food.

2°. Our manner of conducting experiments. Our experiments were always carried out against a strong „excitatory" background. During an experimental session, each dog was given several excitatory conditioned stimuli and only one or two inhibitory stimuli. (This was done in order to keep excitatory conditioned reflexes on a high level). When, afterwards, the inhibitory stimulus was transformed into excitatory, all the trials in the experiments became reinforced. So it is possible that it is much more difficult for an animal to extinguish a single unreinforced stimulus given among other stimuli which are reinforced, than to „equalize" the so far unreinforced stimulus with other stimuli.

As far as the rate of extinction of various stimuli is concerned, our data are similar to those, obtained by other authors (Babkin 1904, Fedorov 1949, Jaroslavceva 1940, Solovieitchic 1940, Stroganov 1929) in conditions of acute extinction. Reflexes to strong stimuli and to firmly established stimuli are extinguished more slowly than reflexes to weaker or less established stimuli. As a new fact there must be considered the unusual difficulty of the extinction in the case when a given stimulus was several times transformed from excitatory to inhibitory and vice versa. We found that in this case the reflex can be extinguished only to a certain degree (in our experiments about 50% of the normal value). It seems as if the stimulus

were unable to become wholly inhibitory. This important fact requires further investigation.

As to the restoration of the extinguished conditioned reflexes, it was impossible, because of the great rapidity of restoration, to grasp whether this process depends on the strength and the fixation of the inhibitory reflex or not. In our experiments the restoration occurred at the same rate after both a short and a long inhibitory training. It is possible that if the training lasted many months the restoration of the reflex would be slower.

There remains the problem whether or not our experimental data can be considered as a direct and accurate indication of the learning process, both in the case of elaboration of inhibitory reflex and its transformation into the excitatory reflex. Our experiments with a diminution of the alimentary excitability seem to show that they cannot. The fact that during the extinction of a reflex there is a stage when its value is, under normal conditions, not diminished, but the diminution can be manifested with the decrease of alimentary excitability, seem to indicate that in the „structure" of the reflex some changes occurred which could not be manifested against the background of high alimentary excitability. On the contrary, if, during the transformation of an inhibitory reflex into the excitatory one, there is a stage when in „normal" conditions the magnitude of the reflex seems to be equal to the normal reflexes but with the diminished alimentary excitability it is lower, this fact again indicates that the „structure" of the reflex was not fully identical with the structure of the other reflexes.

And so the important question arises whether the dissymmetry of the two observed processes (that of inhibition and that of restoration) is not purely apparent and caused only by the excitatory background of our „normal" experiments. We hope to be able to answer this question in following papers.

For the problem concerning the mechanism of the process of restoration of conditioned reflexes those experiments in which the reflex was restored „acutely" in one experimental session seem to be significant. We stated that the reinforcement several times in succession of the extinguished stimulus does not produce the same growth of the reflex as is seen when the stimulus is applied only once daily; in „Cygan" instead of an increase a subsequent diminution of the reflex then occurred, but the next day the reflex to this stimulus became fully restored.

A comparison with our own experience comes to mind, when we learn some text in the evening and although we do not apparently succeed in memorising it, the next day we find that it is wholly assimilated.

How can this fact be explained? It seems that two alternative explanations can be offered. On the one hand, as we pointed out earlier, the diminution of alimentary excitability makes more manifest the difference between a „fresh" and an „old" conditioned stimulus. As at the end of an experimental session, the alimentary excitability may be lowered, this may be the cause of the low value of the freshly restored reflex. On the other hand, if we assume that the restoration of a conditioned reflex is due to the establishment of new interneural connections between the conditioned and unconditioned centre, and that fresh connections are more readily fatigued than the old ones, then the diminution of the new reflex after several repetitions of the stimulus could be explained by reference to the liability to fatigue of the new connections. The question deserves a more detailed experimental analysis.

SUMMARY

1. The chronic extinction of an alimentary conditioned reflex occurs much more slowly than its restoration.

2. The rate of the chronic extinction depends on the fixation of a conditioned reflex and the strength of a conditioned stimulus.

3. The full restoration of the extinct reflex requires only several trials.

4. A reflex extinguished and restored several times seems to become resistant to full extinction.

5. The diminution of alimentary excitability may disclose the partial inhibition of a conditioned reflex which in „normal" conditions is concealed.

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