The Effect of Electroconvulsive Shock on Retention of a Discrimination Habit in Brain-Damaged Rats.

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THE EFFECT OF ELECTROCONVULSIVE SHOCK ON RETENTION OF

A DISCRIMINATION HABIT IN BRAIN-DAMAGED RATS

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Psychology

by

Lempsey F. Pennington, Jr.
B.S., Howard College, 1949
M.A., University of Alabama, 1955
August, 1957
ACKNOWLEDGMENT

The author wishes to express his deep appreciation to the Chairman of his Committee, Dr. Robert Thompson, for his generous assistance, supervision and direction in all phases of this study. Recognition is also made of the contributions and cooperation of Drs. Irwin A. Berg, Bernard M. Bass, M. Ray Loree, Ruth H. Preston, Mary J. Collier, and George C. Kent, Jr.
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ABSTRACT

A measurable temporal unit of correlation between certain molar behavior and its neurological concomitant has been derived from the Perseveration Theory of Müller and Pilzecker. This unit, designated "interference time", is represented by the minimum time between original learning and the presentation of an electroconvulsive shock which produces no measurable decrement in retention. The period is assumed to approximate the "perseveration time" of learning, or the time during which the neurological processes involved in the learning are in a state of lability. The present study attempts to determine the direction of influence of the major variable of brain-damage, produced by extreme anoxia, on the interference time of a discrimination habit in rats.

Forty male and 40 female albino rats were divided into two major groups, balanced in regard to sex. One group was subjected to a simulated altitude of 37,000 feet for one hour by means of a decompression chamber. Two weeks after the oxygen deprivation of this group, all animals of both groups received preliminary training on a black-white discrimination problem under the motivating influence of mild shock. They then received 40 trials on a vertical-horizontal visual discrimination problem. Thirty seconds after the learning trials, half of the animals within each group were subjected to electroconvulsive shock. Two days later, all animals were tested for retention of the vertical-horizontal discrimination habit by the method of relearning.
The analysis of results indicated that those animals receiving both anoxia and electroconvulsive shock suffered the greatest loss in retention, whereas the ones receiving only anoxia retained the earlier learning habit to the same degree as those receiving neither treatment. Since previous investigations have indicated that the degree of memory loss resulting from electroconvulsive shock presented immediately after learning is directly related to the interference time, the implication is that brain-damaged rats demonstrate a longer interference time (and, hence, perseveration time) than do neurologically intact animals. The variable of sex was not influential for learning nor for relearning trials.
INTRODUCTION

Electroconvulsive shock (ECS), used somewhat extensively in the treatment of certain mental illnesses, also constitutes a valuable independent variable for the study of memory. One observation derived from such studies is that permanent or remote memories are more stable than recent ones. This differential susceptibility to interference was suggested as early as 1881 by Ribot in his "law of regression" (cf., 6).

Prominent among later investigations of this phenomenon were the findings of Duncan (4) and Gerard (5), who presented an ECS following the cessation of each trial of a learning series, differentiating several groups on the basis of the trial-ECS interval. Consequent relearning trials revealed that the degree of memory loss was inversely related to the time interval between the end of a trial and the onset of convulsion. Further, Duncan determined a critical period of 15 minutes and Gerard, of one hour, beyond which no deleterious effect on retention was observed.

The results of Gerard and Duncan were complicated by the frequency of presentation of ECS. In an attempt to overcome this objection, Thompson and Dean (17) presented massed learning trials (45 seconds between trials) and a single ECS at varying periods following learning to a criterion. Again, the deficit in retention was inversely related to the length of the criterion-shock interval.
The amount of distributed practice in original learning was found by Thompson and Fennington (18) to be an important variable with respect to the magnitude of memory loss produced by ECS. In this study, the criterion-shock interval was held constant, while the inter-trial interval was varied. The degree of retention was found to be directly related to the inter-trial interval, up to four minutes.

Several studies have indicated that anoxia and ECS have comparable retroactive effects. Hayes (7) found a progressive loss of relearning efficiency with increasing degrees of anoxia, but the anoxic animals developed convulsions, a factor common to ECS studies. Thompson and Pryer (19) found that a ten minute exposure to a simulated altitude of 30,000 feet had a lesser effect on memory decrement than ECS. However, a later study (15) involving altitudes of both 30,000 and 40,000 feet revealed a direct relationship between degree of anoxia and loss in retention. The observed disparity between the effects of ECS and anoxia were explained in terms of differential intensities of interpolated activity.

The foregoing observations have aroused renewed interest in the perseveration theory of Muller and Pilzecker (14). As originally proposed, the theory suggests sustained neurological activity of a gradually decremental nature following the cessation of a learning trial. This activity is assumed to "fix" or consolidate the memory trace and, if interrupted, results in a weakening of the trace.
and decreased retention. This theory has been offered as an explanation for a number of psychological phenomena, such as retroactive inhibition, superiority of distributed practice over massed practice, and reminiscence.

Central to the theory is the concept of "perseveration time" which designates the temporal period between the cessation of training and the complete consolidation of its trace; i.e., the duration of perseverative activity following stimulation. As suggested by Thompson (15), this psychological concept must be recognized as distinct from, though related to, that of "interference time". The latter denotes the maximal period between the cessation of a trial and the introduction of interpolated activity which will produce a decrement in retention. Any equating of the two terms logically requires the assumption that the interpolated activity is of sufficient intensity to disrupt completely the perseverative process.

It is readily apparent that a complete evaluation of the perseveration theory of Müller and Pilzecker must necessarily await the specification of the neurological mechanisms underlying the perseverative process. A reverberatory circuit has been suggested (5) but the length of the interference time would seem to render this explanation inadequate. Some type of metabolic process may conceivably represent perseveration since, for example, the period of enhanced neuronal respiration following stimulation approximates the
interference time in certain types of learning (3). Such an hypothesis was proposed by Thompson and Fryer (19) and has four basic implications. (a) It is assumed that the neurophysiological correlate of learning (and memory) involves some kind of growth in cerebral neurons producing, for example, a decrease in synaptic resistance. This growth may be conceived as involving neurobiotaxis as well as an increase in the population of boutons, a view most recently advanced by Hebb (9). (b) This growth increment, however, is initially in a labile state and may degenerate if the nerve cell undergoes an enforced increase in respiration through, for example, an insufficient concentration of oxygen in cerebral blood. (c) Accompanying this growth is an immediate increase in neuronal respiratory activity which gradually decreases to the resting level. (d) Correlated with the respiratory rise are biochemical reactions which reduce the labile state of the growth increment. Thus, perseveration, according to Thompson and Fryer, may be represented as a transient rise in neuronal respiration—the perseverative period representing the time interval between the onset of heightened respiration and its return to basal level. Consolidation is represented as a decrease in the lability of growth increment produced by processes operating during the perseveration period. Thus, any disturbance in oxygen utilization involving cerebral neurons (ECS, anoxia, etc.) during the perseveration period will cause a decrement in growth with consequent reduction in memory. The magnitude of this reduction will be inversely related to
the time interval between the initiation of perseverative activity and the onset of the disturbance. These statements, although tenuous and speculative, are consistent with the infra-human data on retro-active inhibition which have been summarized.
PURPOSE OF THE EXPERIMENT

It was assumed that the use of anoxia in this study produced generalized cortical destruction. This assumption is based upon Hurder's (10) histological findings of neural deterioration in the brains of rats following exposure to such treatment. A 22 per cent decrease in conducting cells was found within the areas investigated (Brodman's areas 10, 17, 24) following thirty minutes of exposure to a simulated altitude of 30,000 feet. It was anticipated that the degree of anoxia used in the present study would produce sufficient brain damage for the significant altering of the behavior under investigation.

The present study represents an initial attempt to determine the effect of physical alteration of the nervous system upon interference time. Previous studies dealing with retention as a function of brain damage (11, 13) have neglected the temporal aspects of any interpolated activity and are, therefore, not amenable to interpretation within the framework of perseveration theory as it is presently stated. Due to the exploratory nature of the study, predictions as to differences in interference times, as inferred from retention scores, were infeasible. It seems apparent that considerably more intra-species, as well as phylogenetic, comparisons are indicated. This study serves, then, as a predecessor to more specific hypotheses concerning the relationships between gross amount of intact cortex and perseveration time.
METHOD

Subjects

Forty male and 40 female albino rats of the Harlan strain were used as Ss. Their ages at the beginning of preliminary training ranged from 6 to 170 days. They were housed in individual wire cages and fed and watered ad libitum throughout experimentation. Each animal was handled for approximately ten minutes on each of the four days immediately preceding preliminary training.

Apparatus

A cylindrical decompression chamber with a capacity of 30 liters was evacuated by means of a model 50 Cinco-vac pump. A separate exhaust screw valve allowed the manual regulation of decompression. A mercury manometer provided a means of determining the degree of evacuation obtained. The interior of the apparatus was illuminated by means of a 75 watt bulb placed directly above a glass window on top of the chamber.

The discrimination apparatus which utilizes the motive of shock-avoidance has been described in detail by Thompson and Bryant (16). A starting box (5 x 7 x 9 in.) was separated from a V-shaped choice chamber (20 in. in length) by a vertical sliding door. Two windows, 3 1/2 inches square, provided the only escape routes into the goal box (14 x 12 x 6 in.). A vertical partition extended three inches into the choice chamber. The floor of the entire apparatus, with the
exception of the goal box, consisted of transversely-placed bronze rods, 1/16 inches in diameter. The rods of the grid section extending from the base of each window to the end of the vertical partition were separated by distances of 1/4 inch; those of the remaining grid, by 1/8 inch. The electrical circuit was designed so as to allow the independent charging of three portions of the grid; either of the two portions extending to the end of the vertical partition and/or the remaining portion. A transparent plastic top allowed visual examination of the choice chamber. Except as specified, the entire apparatus including the floor of the goal box was painted flat black. In this experiment, all parts of the grid were connected to an A.C. source of 15 volts. Sources of illumination consisted of a 100-watt bulb placed six ft. directly above the choice chamber and two 75-watt showcase bulbs mounted on top of the apparatus at the junction of the starting box and the choice chamber.

The cerebral shock apparatus was the same as that described by Hayes (8), with the modifications made by Thompson (17). A current of 50 ma. was administered by means of alligator clips attached to the ears. A Hunter timer (Model 11110-B) was utilized to regulate the duration of the current (0.5 sec.).

Procedure

Two weeks prior to the beginning of preliminary training, both the male and female js were randomly divided into two groups. One group, consisting of 20 males and 10 females, were exposed for one
hour to a simulated altitude of 27,000 ft. The other served as a control. Anoxia was administered as follows: \( \tilde{s} \) was placed in the anoxia chamber which was then evacuated at the rate of 1500 ft. per min. to a simulated altitude of 27,000 ft. This level was maintained for one hour, after which the chamber was recompressed at the same rate. \( \tilde{s} \) was then removed from the chamber and returned to its cage.

The preliminary training procedure for all \( \tilde{s} \)s was as follows:

On day 1, \( \tilde{s} \) was trained to run from the starting box through the open windows into the goal box. \( \tilde{s} \) was placed into the starting box and the door raised. If \( \tilde{s} \) had not left the starting box within 5 sec., brief intermittent shocks were administered until such a response was forced. Failure to enter the goal box was followed by similar stimulation until such entry was accomplished. The procedure was repeated until \( \tilde{s} \) ran from the starting box into the goal box without the aid of shock.

On day 2, gray cards, through which \( \tilde{s} \) was trained to run, were placed against the open windows at an angle of approximately 45°. This angle was gradually diminished until the cards were flush against the windows. In order to lessen the possibility of the formation of a position habit, one of the cards was locked. The locked card was randomly rotated from the left to the right position.

On days 3, 4, and 5, \( \tilde{s} \) received training on a brightness discrimination, the lighter card constituting the positive stimulus. The negative card was locked and the grid section extending from this card
to the end of the dividing partition was charged. A response to the unlocked positive card admitted S into the goal box, whereas a response to the negative card resulted in shock and inadmission to the goal box. The correction method was used. The locked negative card and the corresponding charged grid section was alternated from the right to the left in a prearranged random order. Again, failure to leave the starting box within 5 sec. or failure to make a choice response within 30 sec. after entry into the choice chamber was followed by a brief shock. An error was defined as an approach response to the negative card which brought S's feet in contact with the charged grid section. Twenty-five trials, with an inter-trial interval of 45 sec. were given on each of the three days.

On day 6, the test problem was given, consisting of the discrimination between horizontal and vertical striped cards, the latter constituting the positive stimulus. The alternating black and white striations were 1/2 in. in width. S was given 30 trials with an inter-trial interval of 45 sec. The training procedure was the same as that employed in the brightness discrimination problem.

Both the brain-damaged (anoxia) and the control groups were divided at this stage into 2 subgroups of 20 animals each (10 males and 10 females). The subgroups were differentiated with respect to the treatment received between learning and relearning. Specifically, one subgroup from each main group received an 80 sec. after the cessation of learning trials, while the other served as a control group.
to which no ECS was given. The four major subgroups thus derived were designated as: the anoxia-ECS group (A-ECS), the anoxia-control group (A-C), the control-ECS group (C-ECS), and the control-control group (C-C).

On day 8, all S's received 30 trials on the same horizontal-vertical discrimination problem. The relearning procedure was identical to that of the original training and the number of errors during this period served as the measure of retention.
ANALYSIS OF RESULTS

Table I presents a summary of the analysis of variance of the errors made during the initial 30 trials. Since no significant differences were obtained, the relearning data (final 30 trials) were subjected to the same type of analysis (Table II). It will be noted that the variance attributed to electroconvulsive shock and to the interaction between shock and anoxia were both significant at the one per cent level of confidence while the anoxia effect alone was significant at the five per cent level. Since the sex variable and all related interactions were insignificant for both learning and relearning scores, the male and female scores were combined for additional analysis.

Figure 1 summarizes both learning and relearning error scores of the four major subgroups (with sexes combined). Although there were no overall significant differences among original learning scores, the graphical representation suggests differences, particularly between group C-ECS and group A-ECS, which might account for the differences between the relearning scores of these two groups. An analysis of covariance, summarized in Table III, was, therefore, performed among the four groups; and, since this proved to be highly significant statistically, adjusted means were computed for each group. These, together with the predicted and observed means, are presented in Table IV. It may be noted that the slight differences between the obtained and the predicted means reflect a very low between-groups
Figure 1

Performance of the Four Major Subgroups (Sex Ignored) on Learning and Relearning the Vertical-Horizontal Discrimination Problem
### TABLE 1

**SUMMARY TABLE OF ANALYSIS OF VARIANCE OF TOTAL ERRORS DURING LEARNING**

<table>
<thead>
<tr>
<th>Source</th>
<th>D.F.</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>1</td>
<td>.05</td>
<td>1</td>
</tr>
<tr>
<td>Anoxia</td>
<td>1</td>
<td>11.25</td>
<td>1.32</td>
</tr>
<tr>
<td>ECS</td>
<td>1</td>
<td>4.05</td>
<td>1</td>
</tr>
<tr>
<td>S x A</td>
<td>1</td>
<td>14.45</td>
<td>1.64</td>
</tr>
<tr>
<td>S x E</td>
<td>1</td>
<td>.45</td>
<td>1</td>
</tr>
<tr>
<td>A x E</td>
<td>1</td>
<td>16.45</td>
<td>1.92</td>
</tr>
<tr>
<td>S x A x E</td>
<td>1</td>
<td>21.25</td>
<td>2.48</td>
</tr>
<tr>
<td>Within</td>
<td>72</td>
<td>8.55</td>
<td></td>
</tr>
</tbody>
</table>

**Total** 79
### TABLE II

**SUMMARY TABLE OF ANALYSIS OF VARIANCE OF TOTAL ERRORS DURING RELEARNING**

<table>
<thead>
<tr>
<th>Source</th>
<th>D.F.</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>1</td>
<td>0.00</td>
<td>1</td>
</tr>
<tr>
<td>Anoxia</td>
<td>1</td>
<td>57.80</td>
<td>8.60**</td>
</tr>
<tr>
<td>ECS</td>
<td>1</td>
<td>64.80</td>
<td>96.70**</td>
</tr>
<tr>
<td>S x A</td>
<td>1</td>
<td>6.05</td>
<td>1</td>
</tr>
<tr>
<td>S x E</td>
<td>1</td>
<td>18.05</td>
<td>2.70</td>
</tr>
<tr>
<td>A x E</td>
<td>1</td>
<td>20.40</td>
<td>5.40*</td>
</tr>
<tr>
<td>S x A x E</td>
<td>1</td>
<td>7.20</td>
<td>1.07</td>
</tr>
<tr>
<td>Within</td>
<td>72</td>
<td>6.77</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>79</td>
<td></td>
<td></td>
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</table>

** significant at the one per cent level of confidence
* significant at the five per cent level of confidence
**TABLE III**

SUMMARY TABLE OF ANALYSIS OF COVARIANCE OF THE 
FOUR MAJOR GROUPS (SEX IGNORED)

<table>
<thead>
<tr>
<th>Source</th>
<th>D.F.</th>
<th>Mean Square</th>
<th>( r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within groups</td>
<td>72</td>
<td>5.3</td>
<td></td>
</tr>
<tr>
<td>Adjusted means</td>
<td>3</td>
<td>2.480*</td>
<td>45.8*</td>
</tr>
</tbody>
</table>

* significant at the one per cent level of confidence
**TABLE IV**

**MEAN ERROR SCORES OF THE FOUR MAJOR GROUPS**

(SEX IGNORED)

<table>
<thead>
<tr>
<th></th>
<th>A-ECS</th>
<th>C-ECS</th>
<th>A-C</th>
<th>C-C</th>
<th>MEANS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obtained (learning)</td>
<td>19.75</td>
<td>10.00</td>
<td>11.85</td>
<td>12.45</td>
<td>11.926</td>
</tr>
<tr>
<td>Obtained (relearning)</td>
<td>12.20</td>
<td>9.15</td>
<td>5.15</td>
<td>4.80</td>
<td>7.825</td>
</tr>
<tr>
<td>Predicted (relearning)</td>
<td>12.73</td>
<td>9.10</td>
<td>5.15</td>
<td>4.82</td>
<td>7.825</td>
</tr>
<tr>
<td>Adjusted (relearning)</td>
<td>11.84</td>
<td>9.70</td>
<td>5.19</td>
<td>4.57</td>
<td>7.825</td>
</tr>
</tbody>
</table>
correlation coefficient between learning and relearning scores 
\( r = 0.048 \).

Table V presents the differences between specific adjusted means for all combinations of treatments. Analyses of the differences by means of t-tests indicated significant differences at the one percent level of confidence between all combinations except groups A-C and C-C. Thus, the implications of the original analysis of variance of relearning scores were substantiated.

The direction of the interaction between anoxia and ECS is of considerable interest. Group A-C did not differ significantly from group C-C, while group A-ECS made considerably more errors than either. It is apparent that anoxia was effective in producing a decrement in retention only when an ECS intervened. Further, since the mean error score of this group \( (A-ECS) \) during relearning was approximately the same as the mean obtained during the initial 30 trials, it appears that virtually all memory of original learning was destroyed by this combination of treatments.
### Table V

**Differences Between Adjusted Mean Error Scores**

<table>
<thead>
<tr>
<th></th>
<th>A-BCS</th>
<th>C-BCS</th>
<th>A-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-BCS</td>
<td>2.14*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-C</td>
<td>0.68*</td>
<td>4.51*</td>
<td></td>
</tr>
<tr>
<td>C-C</td>
<td>7.37*</td>
<td>5.13*</td>
<td>.62</td>
</tr>
</tbody>
</table>

* significant at the one per cent level of confidence
on the basis of hurder's (10) histological findings, it may be inferred that the anoxic animals of the present study suffered some brain damage, although the extent of such damage may not be specified with precision. since the average temporal tolerance to 30,000 feet simulated altitude was approximately 25 minutes (as determined by preliminary investigation with 12 animals), it was supposed that the damage produced by the standard one hour period at 27,000 feet was somewhat extensive. in addition, the fairly high temperature of approximately 86° fahrenheit which prevailed throughout the period of experimentation probably augmented anoxia in its damaging effects, according to histological results obtained by britton and kline (2).

as is true of most behavioral studies involving the destruction of tissue, interpretations are necessarily somewhat tenuous. one possible interpretation is immediately suggested by the classical experiments of bard (1). if sufficient cortex were destroyed to produce the "sham rage" described by bard, it might be anticipated that such a state would interfere with relearning after the noxious stimulus of ecs was presented. that is, brain-damaged animals might be more susceptible to a noxious stimulus than would normal animals. however, it must be pointed out that (a) a period of two days had elapsed between shock and relearning, and (b) the animals which received anoxia but no shock (a-c) performed similarly to those which received neither
IC-C), on both original learning and relearning measures. If anoxia had produced a lowered threshold for emotionality, some differences should have been observed between these groups. Further, the usual indices of emotionality and rage (excessive urination, defecation, biting, etc.) were not conspicuously present among the animals in any of the groups.

Attempts to correlate the results with Lashley's findings of the deleterious effects of brain lesions (11) are subject to the same objections. The lack of a significant difference in retention between groups A-C and C-C clearly indicates that the results must be explained on the basis of a combination effect of UCS and anoxia. At present, no valid hypothesis exists which is considered appropriate.

In applying the results to the concept of perseveration or interference time, the assumption must be made that this period is directly related to the decrement obtained using the minimal learning-UCS interval of 40 seconds. This assumption is based upon previous studies which indicate such a relationship. However, since these studies were not concerned with brain-damage as a variable, it is entirely possible that the assumption is false, leaving it a matter for future investigation.

As applied to perseveration theory, the differences in interference times (as reflected by differences in retention scores) indicate that the growth increment, as discussed by Thompson and Pryer, is in a labile state for a longer period in brain-damaged animals than in
intact ones. This suggests that the "growth" may involve an absolute amount of neural tissue. That is, with decreased neural elements, a longer period of time is required for the involvement of elements sufficient for the attainment of maximal retention. However, such an interpretation must await considerable physiological and behavioral verification.

As previously implied, the present study was designed as a contribution to the currently growing knowledge of variables related to the measurable unit of a perseveration theory; specifically, interference time, as previously defined. It is anticipated that such knowledge will be helpful, if not essential, in the ultimate specification of neurological mechanisms underlying learning and retention.
SUMMARY

Forty male and 40 female albino rats were divided into four equal groups, balanced in regard to sex. Two groups were subjected to 7,000 feet simulated altitude for one hour, while the other two served as controls for this phase of experimentation. Two weeks later, all animals were given preliminary training followed by 40 trials in a horizontal-vertical visual discrimination situation, with mild shock employed as the motivating stimulus. Thirty seconds after the learning sequence, one of the anoxia groups and one of the non-anoxia groups were subjected to electroconvulsive shock. Two days later, all animals were required to undergo 20 additional trials in the same situation. Error scores for both learning and relearning were tabulated.

The factorial design permitted an estimate of the variance attributed to sex, electroconvulsive shock, anoxia, and their respective interactions. Although none of these effects proved significant for original learning, electroconvulsive shock, anoxia, and the interaction between these two were highly significant when applied to errors made during relearning. The direction of interaction was such that errors made by the group receiving both anoxia and electroconvulsive shock were significantly greater than those made by any other group. Adjusted group means were used for comparisons between individual groups.
The results were related to the Perseveration Theory of Müller and Filzecker. Although additional data will be required for any precise interpretation within this framework, the results were in harmony with its present formulation.


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