EFFECTS OF ELECTROCONVULSIVE SHOCK ON MEMORY IN RATS AS A FUNCTION OF THE TYPE OF MEMORY STORED

by

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Experiments were performed to investigate the effect of ECS on memory of a one-trial learning experience, using a behavioural measure not used before in studies of this type. Results show that: (1) some part of the memory of the learning experience survives the ECS; (2) the element that persists is the memory for the novel stimulus; (3) storage of the memory for a novel stimulus, in a form resistant to an ECS, depends upon the motivational state at the time of learning. These results are discussed in terms of theoretical ideas regarding the structure of memory, and some consideration is given to an appropriate experimental approach to the unanswered questions generated by the results.

TABLE OF CONTENTS

Since ancient times, philosophers have wondered at the nature of memory: more recently it has become an important area of objective investigation as well. In part, this interest has been motivated by a desire to improve memory— a goal that is understandable in view of our extensive dependence upon memory in everyday life. But memory is more than just a storehouse of more-or-less important facts, to be retrieved more-or-less efficiently on demand: it is intimately related to our very identity as individuals. It could even be argued that a complete change in a man's set of memories would amount to the destruction of him as an individual, and the creation of a new and different person. Of course, the validity of such an extreme statement (or of any statement about 'memory') depends upon how widely one defines the term. For instance, if one were to include such things as 'political biases', 'religious beliefs', and 'sense of humour' as part of a person's memory, on the grounds that they are shaped by one's experiences in the world, then the totality of our alleged transformation would become quite plausible indeed.

To some extent, any definition is a matter of convenience, and for some purposes an extremely broad definition, as suggested above, would be rather inconvenient. In the investigation of the physiological brain processes underlying 'memory', it is particularly important to be very careful. To give an extreme example, a physiological investigator should probably resign himself to finding great differences between the brain processes involved in learning a telephone number in a few seconds and those underlying the acquisition of a political philosophy in the course of several years. At the outset of any discussion of 'memory', it is important to have a clear understanding of the way in which the term is going to be used, and to this end the following definition is proposed, for 'memory' as discussed in this thesis:

> Memory is a set of neurophysiological events, resulting in a latent behavioral change. This behavioural change consists of a specific response to a specific stimulus.

First, memory is a set of neurophysiological events. This is the material basis of memory, sometimes called the memory trace. It is not well understood how the neurophysiological trace is formed, where it is formed, nor even what it is made of. It seems that both biochemical and electrical events in the brain are involved, but beyond this, little can be said with certainty. Somewhat more detailed treatment of the current theoretical ideas about the memory trace will be given at various appropriate points in the following discussion, (e.g. 'Biochemical Studies', 'Disturbances in Bioelectrical Activity').

Second, memory is latent. This is an easily understood and indisputable quality of memory-- one need not say his name over and over continually to be able to produce it from memory when asked to do so; neither does an animal have to continually press a bar in its home cage in order to be able to do so when returned to a Skinner box. In both cases, the memory is present, in a latent form.

Third, memory leads to a behavioural change. Although the layman might find this part of the definition less obvious than the quality of 'latency', the essentially behavioural basis of our inferences about memory would probably not be disputed by experimental psychologists today. In order to legitimately say that a memory is present, one must be able to point to a behavioural change: if there is no difference in the animal's behaviour after an experience, one cannot say that a memory has been formed. Important problems have arisen in connection with this part of the definition. It may happen that a memory is formed, at least the neurophysiological events occur properly, but for some reason the behavioural change is blocked and does not appear. If one uses only a behavioural measure to test for the presence of memory after the experience, the conclusion in this case would be that memory was not there, but this conclusion would be invalid. Some of the studies to be reported shortly show that exactly this sort of thing has happened in the past. It is difficult to avoid the danger of this sort of mistake completely, but the danger can be minimized if one uses more than one kind of behavioural measure to test for the presence of memory; and in fact the author's own work using this safeguard shows that a memory is present after a treatment formerly thought to produce amnesia.

The fourth part of the definition concerns the notion of specificity. This qualification was included, as a matter of convenience, to remove from consideration a certain class of behavioural change. It has been found that under certain conditions, an animal shows a generalized 'freezing' response to a general situation as a result of punishment. This kind of latent behavioural change, called a 'CER', has been found to have properties quite different from those of other kinds of memory, suggesting that the underlying neurophysiological mechanisms for the CER are probably quite different from those of more specific memories. Since the aim of this thesis was to study the properties of the more specific memories, the usage of the term 'memory' will be such as to exclude the CER, even though the author realizes that CER can in many cases, be seen as a form of more general memory. (Some further discussion of the CER, and of the problems encountered in distinguishing it from memory, will be found in the section on one-trial aversive learning, page 27.)

'Stages' of Memory

According to the suggested definition, it is the neurophysiological changes resulting from a learning experience that constitute the essence of memory. These changes then lead to, or should lead to, a latent behavioural change. In recent years much experimental work has been based upon the hypothesis that there are various intermediate stages between the arrival of the sensory activity from the learning experience, and the final memory.

First, there is a 'sensory' memory stage of extremely short duration in which the sensory input (for instance, an array of letters) is preserved and can be scanned in exactly the same way as the original input itself (Neisser, 1967).

A second form of memory about which there is general agreement can be called 'short-term' memory. Items in this memory stage persist longer than those in sensory memory, particularly if rehearsed, or consciously repeated. But they are still relatively fragile, and can be lost if the subject's attention is directed away from rehearsal.

The third type of memory is called 'long-term' and consists of items that are permanent in the sense that they are no longer subject to loss by such things as prevention of rehearsal, for instance. An important tenet of the multi-stage hypothesis is that short-term memory is different in kind from long-term memory although perhaps playing a key role in its formation.

This description of the overall structure of memory has not gone unopposed. Many of its opponents have held that there is only one mechanism underlying short-term and long-term memory, and the difference between these two 'types' of memory is only one of degree. The remainder of this introduction will consider evidence that supports the 'multi-level' theory, and some important experimental issues that have developed from this hypothesis.

Human Studies

The experiments of Murdock (1960) can be cited in support of the idea that qualitative differences exist between the two types of memory. Murdock used the traditional wordlist task, with the probe technique. Subjects were presented with a list of words, then given a 'probe word' from the list and asked to produce the word that immediately followed the probe. By studying the errors made as a function of the position of the probe word in the list, Murdock was able to show that words accurately remembered included (a) a certain percentage of words from the first part of the list, and (b) a fixed number of words from the end of the list. Further, there was a 'double dissociation' between these two parts of memory in the sense that experimental variables affecting memory for the early items did not influence memory for later items, and vice-versa.

It is difficult to explain results like those of Murdock on the basis of a 'one-mechanism' memory model without making a fair number of *ad hoc* assumptions, but on the other hand, as Deutsch (1969) has pointed out, no one has yet performed an experiment that proves conclusively that the two kinds of memory are qualitatively different.

Further data come from observations of patients given brain lesions for therapeutic reasons. It has been shown that bilateral destruction of the hippocampal region results in memory disturbance. Specifically, these patients are unable to form new 'long-term' memory, although both short term memory and memories acquired before the operation are relatively undisturbed. A dramatic illustration of this syndrome is provided by Drachman and Arbit (1966). People without brain damage can normally memorize a list of 15 to 20 digits after a small number of presentations. But Drachman and Arbit found that patients with these brain lesions were incapable of memorizing a list of that length regardless of the number of presentations; although the patients performed normally on shorter lists (six or seven items) which are generally considered within the holding capacity of the short term memory.

Milner's work (summarized in her 1966 article) with patients that had received lesions in the hippocampus includes several studies designed to uncover the specific nature of the memory deficit observed after these operations. Taking together the results of several experiments by her and others, it can be said that an item can be held in short-term memory for about 30 seconds before decaying. If the item is verbal in nature, retention can be considerably longer if rehearsal is permitted, but a distraction from rehearsal results in immediate loss of the item. For non-verbal items, such as tones or light intensities, rehearsal is not possible, and accurate recall decays in about 30 seconds— presentation of a distraction during the learn-test interval does not materially affect this result. It is worth noting that Milner has found some kinds of learning to be essentially normal, for instance the acquisition of a motor skill.

The patient does not remember ever performing the motor task before, but his performance shows a normal improvement with repeated practice. Perhaps these results suggest that different kinds of information might be stored in memory by means of very different mechanisms.

It is possible to account for results like these without resorting to a 'two-memory' hypothesis-- for example one might suppose that there is a minimum level of strength a memory trace must have to survive as long term memory, and that the hippocampal region is somehow involved with the strengthening of memories. But even though such an interpretation is possible, in this case all the data taken together point persuasively, if not compellingly, to the conclusion that there are important differences and probably qualitative ones, between short-term and long-term memory. Although there are dissenters (Brierly, 1966, Deutsch, 1969), the 'two-memory' hypothesis represents the consensus viewpoint (Broadbent, 1969) and was assumed by the present author in the conception, execution, and interpretation of the experiments reported here.

A second general area of study centers around the formation of long-term memories, and the role played by short term memory in this process. It seems that presence in short term memory for a period of time is a necessary condition for the entry of an item into long-term memory (the work of Milner with the hippocampally lesioned patients shows that this is not a <u>sufficient</u> condition). It has long been recognized that repetition of an item, either covertly by conscious rehearsal, or else by literally repeating the learning experience, facilitates entry of that item into long-term memory. A natural conclusion might be that it is this repetition that is directly responsible for the fixing of the item in long term memory, but this is far from clear. In fact some recent interesting experimental results of Sternberg (1969) suggest that conscious rehearsal simply functions to keep a set of items in short term memory for immediate use, even after long-term memory has been formed. In other words, it may be simply the presence of the item in short term memory (kept there by rehearsal) rather than the repetition *per se* that is necessary for long-term storage.

The Formation of Long-Term Memory - 'Consolidation'

There have been numerous conjectures regarding the links between short-term and long-term memory, and the mechanisms that are involved in the construction of the long-term memory trace. In spite of the considerable effort expended, so far little in the way of clear and definite answers to these questions has been obtained. We know enough to say that the storage process, from the initial input of information to the final storage in permanent memory, is far from simple, and likely involves a series of complicated biochemical and electrical events within the brain. If those events involved in short-term memory could be clearly separated from those involved in long-term memory, an important step would be made toward a complete understanding of the physiological foundations of memory. One of the ways in which many workers have attempted to begin making a separation between the two types of memory has involved investigation of the duration of the 'consolidation' process.

The term 'consolidation' has been used, notably by McGaugh, to refer to the process of long-term memory synthesis. According to the multi-stage hypothesis, memory is in the fragile short-term state for some time after learning, but after a certain interval memory attains the more durable long-term state. It is not yet clear how long the consolidation process takes, and the most widely used experimental procedure for answering this question involves the administration of a presumed amnesic treatment at various times after learning. If the treatment is given before the consolidation process is completed, thus disrupting the sequence of events leading to the formation of long-term memory, then the memory trace would not be consolidated and one would see true amnesia. But if consolidation is complete, then the treatment would have no effect on the memory trace, and the appropriate behaviour would be seen, testifying to the presence of an intact memory. (Another possibility is that the treatment might have an effect on the behavioural measure in some other way, while not affecting the memory trace. In this case, there would not be a true amnesia, but only an interference effect.)

Workers have employed a wide range of amnesic treatments in a variety of experimental situations in an attempt to determine the time necessary for permanent storage of memory. In spite of the apparent simplicity of the strategy, a simple and unambiguous answer to the question of the duration of the consolidation process has been frustratingly difficult to obtain.

Animal Studies

Biochemical Studies

It is accepted almost without question today that formation of the long-term memory trace involves permanent changes at the biochemical level, either in some part of the nervous system, or virtually throughout the brain (John, 1967). There are two biochemical processes that have received serious attention as constituting the medium for long-term memory fixation. These are: (a) shifts in the synthesis of ribonucleic acid corresponding to the specific sensory input of the learning experience, and (b) synthesis of specific brain protein (possibly including transmitter substances) as a consequence of a specific experience. There are some difficulties in the RNA hypothesis (see the review by Booth, 1967) and especially during the past few years most of the research done on these questions has been centered on the protein synthesis hypothesis.

One of the most popular techniques for investigating problems relating to memory in animals has involved the use of potent protein synthesis inhibitors. By observing the effects of these substances on learned behaviours, it is possible to draw inferences about the nature of the mechanisms processing and storing information.

In a typical experiment, Agranoff, Davis, and Brink (1965) trained goldfish in an active-avoidance task, and injected puromycin (a protein synthesis inhibitor) at various times before and after attainment of a criterion of accurate performance. When tested three days later on the same task, fish that were injected just before or just after learning showed no memory of the task. But if the injection was given more than one hour after learning, no effect on memory was observed. Further, the fish that were injected just before learning showed no sign of deficiency in acquisition (as distinct from long term retention) of the task. From these results Agranoff *et al.* concluded that storage of permanent memory had been disrupted, but that neither short-term memory nor learning ability had been impaired.

In another experiment, Davis and Agranoff (1966) were able to chart the decay of short-term memory by injecting the fish before learning, and then testing at several intervals after learning to see whether the short term memory was still present. Their results showed that short-term memory decayed steadily over three days, and had virtually disappeared on the third day. As Agranoff *et al.* (1965) has found, no long-term memory was shown by these animals.

In discussing these experiments, Agranoff (1967) points out that long-term memory is formed within an hour in the uninjected animal, but short-term memory takes three days to decay completely, and concludes that these results taken together constitute strong support for the hypothesis that there are two types of memory.

Results analogous to these have been found by Barondes and Cohen in mice using puromycin (1966) and another protein synthesis inhibitor, acetoxycycloheximide (1968). Like Agranoff, these workers found that: (a) long-term memory was formed within an hour after learning, (b) injection before learning did not impair acquisition, and (c) short-term memory decayed in animals injected before learning. An interesting difference in the two sets of experiments is that apparently short-term memory takes much longer to decay in goldfish (three days) than it takes in mice (six hours-- Barondes and Cohen 1966).

The hypothesis evolving thus far from these experiments was that the protein synthesis inhibitor had prevented, partially or completely, the entry of new information into long-term memory during the period of suppression of protein synthesis, and that a second kind of memory (short-term memory), not sensitive to the drug, was able to influence behaviour until this memory decayed, some time after learning.

However, an important alternative interpretation of the results is possible as Flexner and Flexner (1968) pointed out. According to this explanation, memory storage is perfectly normal, even in the presence of the drug, but proper retrieval of the memory has been prevented somehow by the action of the drug. To test this alternative, these workers repeated the standard puromycin experiment with mice (left-right discrimination in the Y-maze) with two groups: injected five hours before training and injected immediately after training. Five days after learning, each of these groups was divided into two sub-groups: one sub-group received saline injection, the other did not. Five days after the saline injection, all animals were tested for retention. In earlier work, Flexner and Flexner (1967) had shown that under some conditions, a saline injection into the brain can neutralize the amnesic properties of purpmycin in mice, and in this experiment, the reasoning was that if puromycin truly exerts its amnesic effect only by an interference with retrieval, then the effect of puromycin should be reversible even if it is given before learning, when its amnesic effect is strongest. Alternatively, if part of the basic memory trace is lost because of the puromycin treatment, then the saline should not be able to reverse the puromycin effect. Looking only at those animals given puromycin before learning, in which one would expect the strongest amnesic effect, we see that 13 out of 14 animals not given the saline showed memory loss (defined as 1% savings or less on relearning), whereas 9 of 17 animals given saline showed the same degree of loss. Although Flexner and Flexner interpret these results as showing that the saline has not been effective in reversing the effect of the puromycin, an opposite interpretation could also be considered, particularly since the saline-injected animals did show a significant savings effect compared with the puromycin-only animals, when performance was measured in another way. And the efficacy of the saline treatment is even more obvious in those animals given the puromycin immediately after learning. Here, all seven animals given puromycin only showed complete memory loss, whereas 15 of 19 animals given puromycin followed by NaCl showed some degree of retention.

Detailed attention has been given this experiment because of its important bearing on the general issue of long-term memory storage.

Contrary to the conclusions of Flexner and Flexner, it is clear that a strong case can be made that puromycin causes deficits in memory by interfering with access to a normally-stored memory.

In his review article, Deutsch (1969) proposes still another kind of explanation for the protein synthesis inhibitor results— one that is based upon a one-trace interpretation of memory. He proposes that the memory trace is growing stronger in a monotonic way after learning and is affected by the drug (perhaps in ways unrelated to protein synthesis) only if the trace has failed to reach a certain threshold of strength.

The results of Flexner and Flexner cast some doubt on the suitability of the protein-synthesis technique for studying memory functions. It is certainly possible that the observed effect of the protein synthesis inhibitors in the other studies is attributable to an interference effect rather than a true amnesia. Thus, in spite of the attractive picture of the different kinds of memory and their characteristics that the biochemical studies appeared to present, there are still very basic uncertainties about the precise nature of the effects of the treatment, and about the nature of the memory processes affected.

Alternative Amnesic Agents

Probably the best general strategy for approaching the problems involved in memory is to base one's inferences upon results obtained from a wide range of techniques. Consistent with this philosophy, many investigators have employed a number of different methods for producing retrograde amnesia in animals; some of their results will be discussed here.

Anesthesia

A study by Pearlman, Sharpless, and Jarvik (1961) has been widely quoted because of a result at variance with those discussed so far. These workers employed two anesthetic substances in an attempt to induce retrograde amnesia by causing loss of consciousness immediately after the learning experience. The results show the typical time-limited effectiveness of ether and pentobarbitol in causing amnesia for a shock associated with a light cue in a lever-pressing situation. Both these agents could cause amnesia, but only if given within a short time after learning. In contrast, pentylenetetrazol, a convulsive drug, was capable of causing signigicant amnesia for the learning experience even if given four days after the original learning experience. The authors concluded that memory disruption after a post-learning interval must differ qualitatively from memory disruption immediately after learning. Perhaps the amnesia observed in the pentylenetetrazol group injected four days after learning can be attributed to interference with retrieval of the memory, as was apparently the case in Flexner and Flexner (1968) with puromycin.

Immersion

Another kind of amnesic agent has been used in some recent work on retrograde amnesia: immersion in cold water immediately after learning, causing actual lowering of body temperature (Riccio and Stikes, 1969), or only stimulation of the temperature receptors in the skin (Jacobs and Sorenson, 1969). Using a passive avoidance acquired in one trial, Riccio and Stikes showed that immersion in ice water immediately after learning, resulting in a body temperature of 20°C after 20 minutes, caused significant memory decrement on the following day in rats. Memory was indexed by an increase in latency to enter the compartment where shock had been received, and while the cooled rats had a shorter entry latency than the controls (showing impaired memory), the latency had increased over the initial entry latency. Following a second shock-cooling experience, it was found that the experimental animals showed normal memory. These results can be interpreted as showing that a partial memory survived the cooling experience, as the authors conclude, but an equally valid interpretation is that a complete memory survived, but the cooling experience somehow inhibited access to the memory, and this interference disappeared once the memory was strengthened by a second exposure to the shock.

Using a similar passive avoidance step-through task, Jacobs and Sorenson (1969) were able to show that actual hypothermia was not necessary to produce an amnesic effect-- brief immersion in the cold or hot water was sufficient. In their experiment, animals shocked after stepping through a hole into a darkened box showed a latency of 157 seconds till step-through on the following day, while animals given the same treatment plus brief immersion in cold water showed a latency of 40 seconds. On the basis of a comparison of these groups, the authors conclude that the immersion experience has had an amnesic effect. But in a different experiment it was found that animals stepping through and given only immersion (no shock) had a latency of only 6.4 seconds on the following day. No comparison was made between this group and the shock-immersion group with its latency of 40 seconds: possibly such a comparison would show that the shock-immersion group retained some memory of the shock after all. The amnesic effect obtained in this experiment could properly be termed a partial amnesia, brought about in any of a number of ways. The authors suggest a possible explanation for the results— that immersion immediately after learning has the effect of diverting the animal's attention away from the experience of the footshock, with consequence that the memory for the footshock is not well recorded. Another possible explanation is that the stress of immersion is interfering with proper storage.

Confinement

Robustelli and Jarvik (1968) were able to obtain memory impairment by simply confining the animal immediately after learning, either in various parts of the learning apparatus, or even in a glass jar outside the apparatus. It is certainly plausible to interpret their results as showing that disruption of memory has occurred because of confinement *per se*, surprising as this might be, but there is another, more conservative explanation for their results. Possibly the animals show a reduced tendency to avoid on the following day because the fear of the punishing location has extinguished as a result of the confinement within the apparatus. It is true that a similar, though slighter decrement in response was observed when the animals were confined in a glass jar outside the apparatus, but it should be pointed out that the 'start box' of the apparatus was described as 'transparent plexiglass' which possibly resembled the glass jar closely enough to permit some degree of extinction of the fear in the latter.

REM sleep deprivation

Fishbein (1969) has demonstrated a relationship between sleep and memory-dependent performance by training mice in a one-trial passive avoidance task and then depriving them of rapid-eye-movement (REM) sleep for two days. Animals tested right after the sleep deprivation showed no tendency to avoid, but if testing was delayed for 24 hours after the two day REM deprivation, there was no performance deficit, indicating that the memory was still present after the sleep deprivation, but the animals were not capable of using the memory for appropriate performance. In another experiment, Fishbein (1970) deprived the animals of REM sleep before learning took place, using a design analogous to some of the protein synthesis inhibitor studies, in which learning took place normally in the presence of the amnesic agent, but was not apparent upon later testing. In Fishbein's study an analogous effect was found— there was no evidence of memory several days after learning in those animals that were sleep-deprived during learning. This was true even when the conditions were made similar during learning and testing by REM depriving the mice two days before the test. The detrimental effect on memory was found only when the pre-learning REM deprivation was as long as three days: no memory deficit was found in animals deprived of REM for only one day. To account for these results Fishbein suggests that perhaps some as yet unidentified brain substances are needed for formation of long-term memory, and that the lengthy REM deprivation has the effect of depleting the reserves of these substances. It is not clear how this explanation can account for the results in his first experiment, as in that study the animals were non-deprived at the time of learning, and therefore presumably had an ample supply of the raw materials for memory synthesis. The explanation for those results seems to lie rather in the fact that conditions at learning and testing were quite dissimilar for the group tested right after two days of REM deprivation, and more similar for the group tested after two days of REM deprivation plus one day of rest. It would appear that REM deprivation after learning has an interfering effect on long-term memories, but that REM deprivation before learning may have a genuine amnesic effect. But before this latter important conclusion is accepted it would be wise to await more careful study of this phenomenon, employing a wide range of behavioural measures that might be sensitive enough to detect signs of memory in the REM deprived animals.

Gross Alteration of Bioelectrical Events

In general, there are two strategies that have been employed by those investigating the electrical aspects of memory storage in animals: one has been to induce massive and widespread electrical disturbances through a large part of the brain after learning in an attempt to obliterate any coherent patterned electrical activity that might be occurring as a consequence of learning; the second strategy has been to stimulate specific structures in the brain electrically either during or after learning to see if memory depends upon the integrity of electrical activity within these structures. The great majority of electrically-oriented studies has employed the first strategy, although the 'specific structure' approach has become increasingly popular recently. Some of the brain structures that have been given serious attention by researchers include the hippocampus, the amygdala, and the reticular formation. Studies linking these structures with various memory functions will be discussed and criticized in the final discussion section. The remainder of this introduction will concern experiments that have used either of two means for inducing massive and widespread disruption of electrical activity in the brain: cortical spreading depression and electroconvulsive shock.

Spreading Depression

Bureš and Burešová (1963) have shown that the application of potassium chloride to the surface of the brain (resulting in a spreading wave of EEG suppression) shortly after a learning experience is capable of interfering with the memory for that response as indexed by behaviour tested subsequently. Because it is possible to suppress neocortex in one or both hemispheres, the technique has recently found use in increasingly sophisticated studies investigating, for example, relative strengths of memories stored in hemispheres contralateral or ipsilateral to information input (Burešová and Nadel, 1970); or transfer of information in long-term memory storage from one hemisphere to the other (Russell, Plotkin, and Kleinman, 1970).

In an important study, Carlson (1967) presented evidence that different aspects of the learning experience might be stored in different locations. Carlson's animals were trained with only one hemisphere functional (the other was depressed by the KCl), and were later tested on the same task with only one hemisphere functional— either the same hemisphere (group S) or the opposite hemisphere (group E). The reasoning was that animals in group E would not be able to show any memory unless the memory trace was stored subcortically, allowing 'access' by either hemisphere— if the memory trace was laid down in the cortex, then the hemisphere that was non-functional during learning would not contain the memory trace. Briefly, Carlson's findings were that animals in group E tended to spend less time in a punished location than non-punished controls, but did not inhibit their initial entry to the punished location, nor did they show any savings effect when retested on a discriminated active avoidance task.

Her interpretation of these findings was that 'retention of the complex skeletal responses involved in passive and active avoidance requires cortical participation, but that the emotional and cue components of these aversive tasks can be stored subcortically'. Although there has been some criticism of this work (see Deutsch, 1969) it seems clear that Carlson has demonstrated that a given experimental manipulation can cause a decrement when memory is measured in one way (looking at overt performance) but memory is intact when measured in another way (examining more subtle aspects of behavior related to emotional and cue aspects of the learning experience). This kind of refinement in the analysis of the post-learning performance has important implications, as will be seen in the presentation of the author's own experimental work, at a later point.

Further investigations of the spreading depression effect on memory by Albert (1966a) suggest (a) that the amnesic effect is probably related to effects on cortex _per se_ rather than indirect disturbance of subcortical structures; (b) that the amnesic effect cannot be attributed simply to the immediate disruption of patterned cortical activity (since the extent of amnesia is a function of the duration of the depression); and (c) that the important component of the spreading depression seems to be the surface-negative shift in polarity following the cortical spreading depression.

In a second experiment, Albert (1966b) showed that the memory processes can be influenced in various ways by manipulating the polarity of the surface of the brain following learning: application of cathodal polarization to the brain surface following learning resulted in amnesia, but if the cathodal stimulation was followed immediately by a pulsating anodal stimulation, then the performance on the following day was normal.

The cortical spreading depression technique has demonstrated its value in these and other studies, but there are some aspects that limit its usefulness. For one thing, it takes an appreciable length of time for the depression to reach its full strength following application of the KCl (Albert waited 15 minutes before testing to ensure complete depression), and a delay of more than a few seconds in giving the amnesic agent might be critical in the study of some kinds of memory, as will be shown later. Further, there is some evidence that spreading depression is not an effective amnesic agent for some kinds of tasks, particularly those involving appetitive motivation (Blevings, personal communication 1970).

Electroconvulsive Shock

If an electric current of sufficient intensity is passed through the brain of a man or an animal, the result is loss of consciousness accompanied by a general muscular seizure and widespread changes in the electrical activity in the brain. During the forties and fifties this electric current or electroconvulsive shock (ECS) began to be used as a therapeutic measure for depressed psychiatric patients, and it was often noticed that apart from the primary therapeutic effect, the ECS also had an effect on memory. (See Cronholm and Ottoson, 1963 and

Williams 1966 for reviews of ECS effects on human memory).

In 1949, Duncan performed an experiment that showed that ECS has analogous effects on memory in animals. Duncan trained his animals in an active-avoidance task (moving to the safe side of a box within 10 seconds to avoid shock), giving his animals one trial per day. Animals given an ECS within 15 minutes after each trial showed poorer performance over 18 trials than control animals that did not receive ECS. Duncan's conclusion was that the ECS had disrupted the formation of the memory trace, but some aspects of his data present problems for this explanation—these will be considered at a later point.

Further investigations of the ECS showed that the overt muscular convulsion was not necessary for the production of the amnesia (McGaugh and Alpern, 1966, Herz, Peeke, and Wyers, 1966). Taken together with the earlier studies that showed an amnesic effect after administration of anesthetic agents, these studies suggest that rapid loss of consciousness by itself is an effective amnesic agent, if induced immediately after a learning experience.

The extent to which ECS can effectively cause amnesia is a function of a number of experimental variables. Since Duncan's (1949) experiment, it has been known that a delay in the administration of the ECS reduces its effectiveness, presumably because the memory has at least partly consolidated. Thompson (1958) showed that consolidation time varies with the degree of learning (the consolidation period shrinks as the number of learning trials increases), and it varies with the degree of difficulty of the learning (consolidation is short for a simple position habit, but longer for a more difficult discrimination habit). Buresova, Bures, and Gerbrandt (1968) showed that ECS effectiveness can depend upon the particular strain of rat used. In their experiment, an ECS given after learning a position habit in a two-choice situation could cause a significant amnesic effect only in albino rats, and not in hooded rats. Corson (1965) suggested that the effectiveness of an ECS will depend upon both the learning history of the animal and on the kind of information being remembered; he presented data showing that the amnesic effect of an ECS on a simple visual discrimination can be prevented if the animals are given pretraining on a more complex visual discrimination.

Criticism of multiple-trial learning tasks. Suppose that an animal is taught to run from a black compartment into a white one, in order to avoid a footshock. After several trials reliable learning is obtained, then the animal is given an ECS to disrupt memory. On the following day, the animal shows an apparent amnesia— that is, compared to control animals that did not get an ECS, this animal does not run into the other compartment in time to avoid the footshock. One possible conclusion is that there really is an amnesia— that the ECS has wiped out the memory for the appropriate behaviour. But an equally valid explanation is that the ECS itself is a punishment, and the animal avoids repeating the response that was followed by an ECS on the previous day. This question of the possible punishing effects of the ECS will be considered in some detail later, but for now it is clear that a great many of the studies employing multiple trial learning designs in which this possible complication exists, are somewhat suspect. For example, returning to the Duncan (1949) experiment, we see that all of the animals that were given an ECS after each trial showed an initial improvement in avoidance, but then actually regressed in the performance. This result is exactly what one might predict in applying an 'aversiveness of ECS' interpretation of the data.

But apart from the possible confounding effects of the aversiveness of the ECS there is another criticism that is more serious, and has succeeded in discouraging the great majority of investigators from continuing to use multiple-trial learning tasks. The criticism is that one has no precise control over the learning-ECS interval, simply because it is impossible to pinpoint where, in the course of 30 trials and 10 criterion trials, an animal 'learns', for instance, a black-white discrimination. And if memories are sometimes permanently stored within minutes or even seconds after learning (this will be discussed more fully later), then precise control over this learning-ECS interval is mandatory.

<u>One-trial passive avoidance</u>. To avoid these difficulties, a different kind of learning task was designed about 10 years ago. The animal (usually a rat or mouse) was put onto a small platform, slightly elevated above the floor

of the apparatus. Usually, the S will step down within a matter of a few seconds. If a punishing footshock immediately follows the step-down, then on subsequent return to the platform, the animal will not step down for several minutes. Thus, an increased latency is the measure of learning in this situation. Now if a naive animal is placed on the platform, allowed to step down, given the punishing footshock, and then given an ECS, the subsequent behaviour differs from that of the non-ECSed rat. The ECSed animal shows no increase in latency, or more precisely, the ECS group shows a significantly lower latency than the footshock/no-ECS group (Madson and McGaugh, 1961). As Madson and McGaugh point out, this procedure avoids both of the criticisms directed against the multiple-trial learning studies using ECS. First, the learning-ECS interval can be more precisely measured; and second, any punishing effects of the ECS would be expected to summate with the punishment of the footshock, resulting in longer, not shorter latencies on the following day.

Another procedure designed to avoid the two criticisms was employed by Weissman (1964), modeled after Pearlman et al. (1961). Here, animals were first trained to press for water reinforcement in a standard operant conditioning apparatus, then punished with a footshock after a lever-press. The measure of memory for the foot-shock was the extent to which bar-pressing was suppressed on the following day. Animals that were given an ECS after the punishing shock showed significantly higher bar-press rates when returned to the apparatus, showing a memory deficit. As in the step-down task, there is a more precise control possible over the learning ECS interval compared to that possible in the multiple-learning studies. As well, the effect seen cannot be attributed to the punishing effects of the ECS, which would presumably summate with the punishment from the footshock, resulting in even more response suppression, rather than less, as was observed.

Using this type of experimental design, several investigators have attempted to determine the 'consolidation time' of the memory for the footshock, but there has been little agreement in the values obtained in different studies. In Weissman's study, an ECS given 40 minutes after learning significantly affected memory, whereas in Madson and McGaugh (1961) an ECS was not effective after more than 15 minutes post-learning. And Chorover and Schiller (1965), using the step-down design, showed that ECS given later than 10 seconds after learning was not effective as an amnesic agent. In his 1968 paper, McGaugh tried to explain these differences in 'consolidation time' by supposing that in a simple learning task, the memory would enter long-term storage, or 'consolidate' more quickly, and would take longer to do so in more complicated tasks. However, it is not likely that this can be the entire explanation-- for instance, it is not clear why it should have taken Weissman's rats 40 minutes to consolidate the memory for a very simple response inhibition task. A more convincing explanation has been offered by Chorover and Schiller (1966); they suggest that the effect of an ECS upon memory will depend upon whether it is a CER or a more specific memory that controls behaviour. In their study, animals given unescapable shock in a small compartment showed a reduced tendency to enter that compartment on later testing, but that this memory could be wiped out by an ECS given as much as four hours later. Alternatively, animals given a chance to escape the shocks in the small compartment showed a tendency to avoid that could not be disrupted by an ECS given two minutes later. Taking these results together with other results obtained in the same study, Chorover and Schiller concluded that animals given unescapable shocks formed a general conditioned emotional response to the cues present in the apparatus. That is, there was no specific response that was selectively inhibited, nor was there any specific avoidance in evidence-- the animals simply 'froze' and remained immobile during the test period. It was this general 'freezing' reaction that was sensitive to disruption by an ECS for several hours after learning. A very different kind of memory was formed, however, in animals that were allowed to escape the shocks. These rats did not show the CER-- instead, there was simply an avoidance of the specific place where the punishment was received. And this more specific memory was 'consolidated', or permanently stored, very quickly after learning.

Pinel and Cooper (1966a, b) showed that the 'passive avoidance memory' seen in animals on the day following punishment can be attributed to CER-produced immobility. Further, the CER tends to grow, or 'incubate' monotonically after the punishing experience, and an ECS given after learning has the effect of arresting the development of the CER. Thus, the 'amnesia' seen in the ECS animals during retest is only the absence of the CER. In a later experiment, Pinel (1970) tried to separate this CER-produced avoidance from a true memory for the punishing stimulus, and study the effect of the ECS on these two different processes. The results he obtained can be seen in a comparison of three groups:

(A) Learn ——————— Test
1 hour

(B) Learn ——————— ECS ——————————— Test
1 hour 23 hours

(C) Learn ———————————————————— Test
24 hours

As expected from previous studies, Group C showed a passive avoidance of the punished location during testing, and also showed substantial freezing (Pinel observed both the activity and avoidance behaviour of his animals). Also as expected, Group B showed poor avoidance, and little freezing. So far, the results are consistent with the notion that avoidance depends on CER-induced freezing, which can be disrupted by an ECS. The problem for this interpretation comes from the performance of Group A. Like Group B, this group showed little freezing, implying that after one hour there has not been much incubation of the CER. But unlike Group B, this group showed excellent avoidance of the punished location. Pinel concludes that since the passive avoidance seen cannot be explained by 'freezing', it must be due to a true memory for the punishing stimulus. And since the animals in Group B do not show the avoidance, this memory must have been disrupted by the ECS, even though this was administered an hour after learning. Since Pinel's measures of learning and of 'freezing' are somewhat atypical (percentage of S's avoiding for 500 seconds; percentage of S's freezing at least once, where 'freezing' is immobility for 15 seconds), and his results are at variance with other studies, complete acceptance of his conclusions should await replication. However, it seems that the eventual explanation of these results will include provision for the interaction as well as the separability of the CER incubation and specific memory consolidation processes. For instance, it may have been that the developing CER interfered with the consolidation process, thereby making the more specific memory more vulnerable to an ECS given after one hour. It also seems that the use of both active and passive avoidance groups in a design similar to Pinel's would be of help in determining the role of the CER in controlling behaviour at the various intervals between one and 24 hours.

Kopp, Bohdanecky, and Jarvik (1966) claim to have shown consolidation of a specific memory that continues to be sensitive to ECS-disruption for several hours after learning. Animals given a punishing footshock after stepping through a small doorway would inhibit step-through on the following day, unless an ECS was given, and in this experiment ECS was effective even six hours after learning. The authors concluded that a consolidation process of considerable duration was being disrupted. To eliminate the possibility that CER incubation was the actual process being affected, other animals were given a punishing shock after removal from the apparatus. These animals did not show an increased latency to step through the doorway of the apparatus, and the authors reasoned that a CER had not been formed in this situation. But as Spevack and Suboski point out (1969), this CER control must be rejected as inappropriate. There is no reason to think that a footshock given outside the apparatus will necessarily be associated with cues inside the apparatus, so the failure of these control rats to show a CER has no relevance to the question of CER formation in those rats shocked within the apparatus.

In order to ensure that the memory in question is in fact a specific memory rather than a CER affecting performance, some workers have employed a discriminated avoidance task, in which memory is shown by the ability to make a discrimination and hence cannot be shown by an indiscriminate suppression of all behaviour.

Suboski, Black, Litner, Greener, and Spevack (1969) investigated the question of duration of consolidation using a discriminated avoidance task that could be learned in one trial. Rats were first trained to press a bar for food reinforcement, then one wall of the apparatus was illuminated and the first subsequent bar-press was punished. Later, animals showed suppression of bar-pressing when the wall was illuminated, but not when the wall was dark. An ECS was able to disrupt this selective suppression (with the result that no response suppression during illumination was seen) only if given within 20 seconds after learning.

This study avoids the difficulties of Kopp et al. (1966), but without a clearer idea of the behaviour of the animals during response suppression, it is not possible to say anything certain about the underlying memory events. It is possible that there is still a CER that is suppressing all behaviour-- triggered only by the specific cue of the illuminated wall-- rather than by the entire apparatus, as in earlier studies. Even at the longest learning-ECS intervals (around 50 minutes) the performance of the ECS group on the discrimination was significantly poorer than that of the no-ECS group. Effectiveness of an ECS after such a delay is typical more of CER than of true memory, again suggesting a possible involvement of CER in the response suppression, and that the ECS might have partially disrupted the developing CER.

Pfingst and King (1969) taught hungry rats to run through a T-maze to obtain food, forcing them to go both to the left and right arms. Then eating in the right goal arm was punished by a footshock, following which the animals received an ECS after various intervals. The measure of memory was the percentage of left-arm choices in a free-choice situation on following days, and on this measure rats showed a high preference for the left unless the ECS was given within 20 seconds after learning. Animals given ECS that quickly showed no change in the goal arm that they chose, thus demonstrating amnesia for the experience of the footshock compared with the other groups. The results clearly cannot be attributed to any CER interference with behaviour, since the behavioural measure was based upon the direction of choice, not upon the occurence or non-occurence of a response.

A most promising approach to the difficult problem of separating incubation of CER from specific memory is exemplified by Blanchard and Blanchard (1970a, b). These workers showed one-trial acquisition of avoidance, both with and without a CER. The crucial variable was found to be the saliency of the dangerous location. If the shock was simply delivered in one part of the apparatus, not obviously different from the rest, then subsequent return evoked a 'freezing' reaction. Alternatively, if the shock was delivered by a clearly identifiable source (a metal box with a flashing light inside), then subsequent performance showed no contact with the box (avoidance) but without freezing— the animal moved freely about in the rest of the apparatus. No ECS was given in these studies, but it is obvious that the design permits clear control over the kind of memory being formed and is a potentially most valuable approach to these problems.

While many of the difficulties involved in separating CER from memory may be partly dispelled by an approach like that of Blanchard and Blanchard, there are other problems involved in the use and interpretation of one-trial passive avoidance studies. There is good reason to believe that after a punishing footshock, the animal is in a high state of arousal that continues to the administration of ECS. The interaction of high arousal and ECS apparently has uniquely severe effects upon such things as the post-ECS EEG pattern (Chorover and DeLuca, 1969), so it is not impossible that the 'picture' of memory function that is emerging from these studies is accurate only for memories formed under very special conditions, and is therefore misleading. For these and other reasons, some workers have recently turned to appetitively-motivated learning tasks.

One-trial appetitive learning. - The definition of 'amnesia'. In 1967, Schiller and Chorover performed an experiment using appetitive motivation which, although not precisely a one-trial learning task, provides a clear example of an experimental result encountered frequently already. Schiller and Chorover trained their rats to run through a Hebb-Williams maze, using a variety of problems. When the animals were well-used to running through the maze and learning new problems, the experiment proper began. A new experimental problem was presented, and the animals were given one trial. Following this, some rats were given an ECS (immediate or delayed). On the following day, animals given an ECS performed more poorly than non-ECSed rats (made more errors traversing the maze), but performed significantly better than rats that had never seen that particular problem before. This intermediate performance indicates some degree of retention, and following Lewis (1969) this effect will be defined as a partial amnesia. According to Lewis, complete retention is defined as performance significantly better than the no-learning control group, and not significantly poorer than the learning-no-ECS group. Complete amnesia is defined as performance significantly poorer than the learning-no-ECS group and not significantly better than the no-learning control group. (See Figure 1)

Tenan (1965) designed a new procedure that permitted one-trial learning, and is especially suitable for detecting any memory that might survive the ECS. First, animals are put on cyclic water deprivation, and then are put into an enclosed box once a day when they are maximally thirsty. One wall of the box has a recessed niche centered two inches above the floor, into which the animal can insert his head. A photocell-counter circuit records the number of niche explorations made during a five minute period. Each animal is given five minutes in the box every day for four days. On the fifth day, the animals were divided into five groups. Four of the groups were reinforced— that is, found a water nozzle in the niche, and were allowed to drink for 10 seconds. Following this, one group was given an immediate ECS, one was given a delayed (by three hours) ECS, one was given an immediate footshock, and one was given a pseudo-ECS (ear clips attached but no current passed). The fifth group was neither reinforced nor given ECS. The measure of learning was the increase in the number of niche explorations on the following day, and by this measure the immediate ECS group showed total amnesia— they explored significantly less than the pseudo-ECS group, and not significantly more than the non reinforced control group. On the other hand, the animals given the delayed ECS showed retention in that they explored more than the no-learn controls, and not significantly less than the learn, no-ECS animals.

To control for possible aversive effects of the ECS, Tenan included the group that was given reinforcement followed immediately by a footshock, and found that their performance was indistinguishable from that of the group receiving reinforcement and no ECS. However, this can be seen as an inappropriate control, since there is no good reason to suppose that the aversiveness of a footshock affects performance in the same way as the aversiveness from an ECS. A helpful control would be a group that did not learn but received an ECS after exploring the niche.

Using the same procedure as Tenan, but incorporating the no learn-ECS control, Pinel (1969) was able to show a short gradient, or 'period of consolidation' for the memory of the water. An ECS was effective in causing amnesia, as defined above, only if administered within 10 seconds after learning (Experiment 1).

With a slightly different procedure, but one in which again the measure of memory was the number of times a particular response was emitted, Herz (1969) reported complete amnesia for water reinforcement when the ECS was given within 20 seconds of learning.

<u>The present investigation</u>. Several of the studies reviewed here have demonstrated the dangers of looking at only one kind of measure of behaviour in order to assess the persistence of memory after an amnesic treatment. For instance, the work of Carlson shows that one behavioural measure may not show the existence of memory, but examination of more subtle measures of performance shows that at least some aspects of the

learning experience are still present (this point will be examined in more detail later).

The present study was undertaken with the objective of examining the formation of the memory for a one-trial learning experience under appetitive motivation, to see if any aspects of the memory would survive an ECS, and if so, to identify those elements of memory that are lost after ECS, and those that remain. Because of its simplicity, freedom from interference from the experimenter (the animal is freely moving within an enclosed box), and apparent similarity to rapid-learning situations in the wild, the design of Tenan was chosen as the primary experimental tool.

P A R T I

MEMORY AND AMNESIA AFTER ECS
IN A ONE-TRIAL APPETITIVE LEARNING SITUATION

Experiment 1

The first experiment to be reported was a replication of the one-trial appetitive learning study of Tenan (1965), but incorporating an additional measure of behaviour: the position of the animal in the box on the day after learning. Pilot work had suggested that this would be a more sensitive measure of memory than would 'number of niche explorations'— the measure used in previous studies. The failure of previous studies of this type to show a memory of the learning experience after an ECS might have been due to an insufficient sensitivity of the behavioural measure that was used.

The present experiment was designed to test the hypothesis that ECS does not completely disrupt memory, and that some evidence of memory can be found if a sensitive enough behavioural measure is used.

Method

Subjects

Subjects were 30 naive male hooded rats, 225-250 grams at the start of the experiment. Rats were housed two per cage upon arrival.

Apparatus

The apparatus was identical to that employed by Pinel (1969). Briefly, a cubic box 16 inches on a side was fitted with a grid floor, and a niche 2 x 2 x 2 inches was fitted into the center of one wall, 2 inches above the floor. One inch back from the edge of the niche, a photocell was fitted to the apparatus.

Procedure

Two days after arrival, the animals were put onto a 23 hour water deprivation schedule, and on the third day of water deprivation, Day 1 of habituation began. Animals were placed into the box and allowed to explore for five minutes, during which time a record was kept of the number of explorations made. Days 2 and 3 were the same as Day 1. On Day 4, the same procedure was followed except that the experimenter, after removing the animal, briefly rubbed both pinnae. After removal on Day 5, the ear clips were briefly attached to the pinnae. (Pilot work had shown that this procedure greatly reduced the trauma of ear clip attachment during the ECS administration on Day 6.) On Day 5, a record was kept of the latency of the first niche exploration, for each animal. After the Day 5 session, animals were divided into four equal groups, balanced with respect to the total number of explorations made during the habituation period. The procedure on Day 6 depended upon the group to which the animal belonged:

L-NECS-- water nozzle present in the niche, S allowed to drink for 10 seconds; removed, given a sham ECS (ear clips attached, but no current).

L-ECS-- same as above, except that 50 ma AC .5 seconds passed through the clips after attachment.

NL-NECS-- no water nozzle presented in the niche; animal removed 10 seconds after first exploration of the niche; ear clips attached but no current passed.

NL-ECS-- same as above, but ECS was given as in the L-ECS group.

Following Pinel's procedure, no water was given to the animals after the Day 6 session. The procedure for Day 7 was similar to that for Day 5, with the exception that the experimenter continually monitored the position of the animal within the box. Using a stopwatch, E recorded the total amount of time the animal spent in the side of the box containing the niche. The animal was considered to be in the 'niche half' of the box if both of its forelegs were on or over the half of the grid floor closest to the niche. Since the same person administered the treatment on Day 6 and measured the position on Day 7, the procedure was not, strictly speaking, 'blind'. But by scrambling the order in which the animals were run on Days 6 and 7, and by not re-checking the treatment before the test period on Day 7, the experimenter was not consciously aware of the group membership of any given animal. In any case, the error due to any unconscious bias is probably minimal, owing to the relatively straightforward character of the measure used. A further safeguard against this kind of contamination of the results was employed in Experiment 7, and will be described in the method section of that study.

All statistical evaluation was based upon the Mann-Whitney test; p-values given represent the 2-tailed probability of the null hypothesis.

Results and Discussion

Following Tenan, the measure of memory for each animal was the number of niche explorations on Day 7 minus the number of niche explorations on Day 5. The results show reliable learning in the L-NECS rats, since these animals show a significant increase in niche exploration compared with the NL-NECS animals ($U=.5$; $p < .002$). As Tenan and Pinel found, the L-ECS animals do not show memory by this measure: the L-ECS animals do not show a greater mean increase in exploration than the NL-ECS control group ($U=10$; n.s.), and show less of a mean increase in exploration than the L-NECS animals ($U=5$; $p < .05$).

The results in Figure 3, however, show that there has been a retention of some kind by the L-ECS group, as they spent significantly more of their time in the side of the box containing the niche than did the animals in the NL-ECS group ($U=5$; $p < .05$).

In Figure 4, the initial latency on Day 7 for each group is presented, and there is a suggestion of an effect of the learning experience in the L-ECS group, compared with the NL-ECS control group. The difference between these groups mirrors the trend indicated by the two no-ECS groups: in both cases the discovery of the water by the learning group tended to lower the latency to first exploration on the following day, relative to the non-learning group.

It is clear from the results that, contrary to the conclusions of Pinel and Tenan, some aspect of memory survives an ECS given 5 to 10 seconds after a one-trial appetitive learning experience. One possible explanation for the performance of the learning-ECS group involves supposing that the ECS has had no effect on memory whatever, but has depressed activity. Thus the animals do not show an increased frequency of head-poking, because every kind of activity has been inhibited by the ECS. But the preference for the area around the reinforced location would not be affected, because this behavioural measure is less sensitive to changes in activity level. Routtenberg (1965) has found an effect of a single ECS upon activity in an open field (animals given an ECS showed less locomotion), but his animals showed the greatest effect six hours after the ECS and there was no effect on open field activity measured eight hours after the ECS. Furthermore, other workers have found no evidence of a depression of activity 24 hours after a single ECS (Herz, 1969; Greenough & Schwitzgebel, 1966; Peeke, McCoy, and Herz, 1970). However, the possibility remained that in the present experimental situation, with the animal water-deprived 47 hours at the time of testing, and in an enclosed box to which it was habituated, ECS might have an effect upon general activity, so Experiment 2 was performed to test this possibility.

Experiment 2

Method

Subjects

Subjects were 20 naive, male, hooded rats, weighing 225-250 grams housed two to a cage.

Apparatus

Apparatus was the same as that used for Experiment 1, except that the area under the grid floor was marked off into 16 equal squares, 4 inches to the side.

Procedure

All animals were placed on 23 hour water deprivation on the day following arrival. Three days later, the experiment began; all animals were given the five days of habituation to the apparatus. During the habituation period, activity was measured for each animal. The activity measure was the total number of lines in the 16-square grid crossed by the animal during the five minutes, recorded by the experimenter looking down at the animal through the one-way glass. On Day 5, animals were randomly divided into two equal groups, and on Day 6 they received either an ECS or a sham ECS 10 seconds after the first niche exploration. On Day 7, all animals were given the usual test session, during which activity was recorded.

Results

In Figure 5, the activity on days two through seven of the two groups is expressed, as a percentage of the activity measure on Day 1. Both groups show a decline in activity that is probably due to habituation, but there is no difference between the groups either before or after the ECS.

Experiment 3

The results of Experiment 1 suggest that some aspect of memory survives the ECS, and raises the possibility that ECS might not cause amnesia at all, but that the 'exploration frequency' (the measure showing amnesia in this and previous experiments by others) might be artificially depressed by the ECS, resulting in an apparent amnesia. This behavioural depression might occur as a result of some ECS-associated aversiveness linked with the specific response of head-extension into the niche.

The question of the aversiveness of ECS has been debated for many years, and it is obviously of critical importance for the interpretation of results obtained from studies, like Experiment 1, employing appetitive motivation. A view that has gained wide acceptance is that put forward by McGaugh (1966): ECS can indeed have aversive properties, but these appear only after several administrations of the ECS, never after only one. There are a number of studies supporting this view, showing that in the typical one-trial learning experimental situations, ECS given only once does not have aversive properties (Hudspeth, McGaugh, and Thompson, 1964, using the step-down; Chorover and Schiller, 1965, step-down; Gerbrandt, 1965, step-down; Riddell, 1969, step-down; Kesner, Gibson, and Leclair, 1970, step-down; Heriot and Coleman, 1962, bar-press; Herz, 1969, niche exploration; Pinel, 1969, niche exploration). Recently, however, there have been reports that even when only one ECS is given, there are some signs of ECS-induced aversiveness (Lewis, Miller, and Misanin, 1968, step-down; Misanin, Smith, and Miller, 1971, step-down). Some doubt, then, has been cast upon the notion that a single ECS is entirely free from aversiveness.

There is an additional reason for carefully examining the possibility that the results in Experiment 1 may be due to aversiveness of the ECS: the aversiveness may be difficult to detect because of the nature of the head-poke measure. Pinel concludes that the ECS has not been aversive because the no-learn, ECS group did not show a significant drop in head-poke frequency after the ECS. But this may be because the exploration frequency in that group was already so low that the aversiveness could not drive it much lower. On the other hand, the learn-ECS group would show a significantly lower frequency than the learn-no ECS group, since the learning experience would have the effect of elevating the response frequency. Once the response frequency was elevated by finding the water, then the aversiveness from the ECS could be seen more clearly.

To test the hypothesis that the results of Experiment 1 could be explained by an aversive effect of the ECS associated with the niche-exploring response, Experiment 3 was performed.

Method

Subjects and Apparatus

Subjects were 60 male hooded rats, 225-250 grams, naive at the beginning of the study. Apparatus was the same as that used in

Experiment 1.

Procedure

At the beginning of the experiment, the subjects were divided into five groups of 12 each, as follows:

L-NECS
NL-NECS
L-ECS
NL-ECS
L-ReExpose-ECS

The first four groups were exactly analogous to the four groups of Experiment 1. The fifth group was a Learning, Re-Exposure, ECS group. These animals discovered water on Day 6, drank for 10 seconds, and were removed like subjects of the L-NECS group. Ten minutes after learning, the subject was returned to the apparatus. Usually within seconds, the animal would go to the niche, put its paws on the edge, and insert its head. At this point, the animal was removed and immediately given an ECS. Usually the animal was just making contact with the nozzle at the time of removal, although some of them oriented toward E as the lid to the box was opened, and others managed to get a few extra licks of water before removal. Subsequent analysis showed no difference among the animals. Although Pinel (1970) reported that, in a one-trial passive avoidance situation, an ECS could disrupt memory when given as much as an hour after learning, Pinel (1969) reports that, in an appetitively-motivated situation like that used in Experiment 1, 10 minutes is sufficient time for the establishment of an ECS-resistant memory trace.

That is, an ECS given 10 minutes or more after the animal is removed from the learning situation causes no decrement in subsequent response level. But if the behavioural deficit after the ECS is due to an aversiveness of the shock, then possibly the 10 minute delay group of that study does not show the deficit because the negative reinforcement has been delayed too long. If so, the learning-ReExpose-ECS group in the present experiment, in which the head-poke response is immediately paired with the ECS, should show, like the L-ECS group, significantly less retention than the L-NECS group, and no more retention than the NL-ECS group.

Results and Discussion

Figure 6 illustrates mean retention scores of the five groups (as defined in Experiment 1). As can be seen, the L-ECS group showed significantly less retention ($U=27$, $p < .05$) than the L-NECS group, and was not significantly different from the NL-ECS group ($U=39$, $p > .1$), thus showing amnesia. (No position measures were taken, as the experiment was designed to examine possible effects of ECS on the head-poking response.)

In contrast, the L-ReExpose-ECS group showed significantly more exploration than the NL-ECS group ($U=8.5$, $p < .002$), and was not significantly different from the Learn-No ECS group ($U=52$, $p = .40$), thus showing complete retention.

It is clear from these results that the ECS effect on the head-poking response is not a simple matter of aversiveness competing with the memory of the reinforcement. The most natural and obvious conclusion to draw is that ECS has had an effect on the memory of the learning experience, or some aspect of it, and that this ECS effect is no longer present when administration of the ECS follows learning by 10 minutes or more.

The results also provide evidence against the 're-activation' hypothesis (Misanin, Miller, and Lewis, 1968). In that paper, Misanin *et al.* adduced evidence against consolidation theory by showing that a re-exposure to the situation followed by an ECS produced 'amnesia' even if the re-exposure ECS pairing took place several hours after original learning. The argument was that the ECS effect could not be interpreted as a disruption of a rapidly-completed consolidation process, because the same ECS effect could be observed hours after learning, when 'consolidation' should have been complete. Using the same passive avoidance situation (step-down), Dawson and McGaugh (1969) failed to replicate the findings of Misanin *et al.* Banker, Hunt, and Pagano (1969) also failed to replicate Misanin *et al.* using the step-down, and using a discriminated avoidance. The present results suggest that the 're-activation' effect may not be seen in appetitively motivated tasks either.

Experiment 4

When a rat unexpectedly finds water in a familiar environment, there are at least two processes occurring, even though they might be so close together that they are considered to be one: first, the animal realizes that there is 'something new' in the environment—in this case, in the recessed niche. And secondly, the 'something new' is identified as water.

If one assumes that an animal would have a slight tendency to investigate a novelty that suddenly appears in a familiar environment, then a fourth testable explanation for the results in Experiment 1 can be offered: the ECS has the effect of disrupting the memory for reinforcement, but the 'novelty' memory is intact.

Pilot work done before Experiment 1 suggested that this novelty memory might survive the ECS and could possibly influence the animal's subsequent behaviour. Therefore, the two groups of Experiment 4 were run concurrently with the animals in Experiment 1 and will be discussed together with them.

Method

Subjects, Apparatus, and Procedure

Subjects (20), apparatus, and procedure were exactly the same as described for Experiment 1, up to the end of Day 5. On Day 5, rats were divided into two groups, balanced according to the number of niche explorations made on Days 3, 4, and 5. On Day 6, all subjects found a novel stimulus in the niche. For half the subjects of each group, this novel stimulus was a dry water nozzle, for the other half it was a coil of wire (this was done to test an experimental hypothesis that was later discarded). Subsequent analysis showed that the nature of the novel stimulus discovered had no effect on the results. Ten seconds after the discovery of the novel object (insertion of the head into the niche), the animal was removed and given either an ECS or a sham ECS. Four of the animals in the Novelty-sham ECS group were discarded on Day 6 because of failure to explore the niche during the five minute period.

Results and Discussion

Figure 7 shows that the Nov. ECS group shows the same tendency to occupy the niche half of the box on Day 7 as does the L-ECS group, in that Nov. ECS animals spend more time in the niche half than the NL-ECS rats ($U=17$, $p < .05$).

In Experiment 1, it was noted that the Learning-ECS group showed a non-significant tendency toward a lower latency of exploration on Day 7 than the NL-ECS group. Figure 8 shows that the same tendency is exhibited by the Novelty-ECS group.

Figure 9 shows that there is no difference between the Nov. ECS and the Nl-ECS with respect to total niche explorations on Day 7: this mirrors the comparison between the L-ECS and the control group.

Thus, in niche explorations, initial latency, and time spent in the niche half of the box, the L-ECS group and the Novelty-ECS group behave in the same way. (The measurement of initial latency, because it always shows the same effect as 'time spent in niche half' was omitted as a measure for the remaining experiments.)

Turning to the non-ECS groups, Figure 9 shows an apparent increase in niche explorations for the Nov. Nothing group, but this increase is not significantly greater than that shown by the NL-NECS animals ($U=11$, $p > .1$). Of some interest is the finding that the Nov. Nothing group does not show an increased tendency to occupy the niche half of the box (Figure 7). A possible explanation for this lack of interest in the niche half on Day 7 is that the animals classified the novel object as 'uninteresting' on Day 6— that is, the object was not capable of sustaining investigation because the rat had classed the object as non-reinforcing. Evidence for this is the informal observation that most of the rats discovering the novel stimulus turned away to other areas of the box by the end of the ten seconds, compared to the rats discovering water, virtually all of which continued drinking during the entire ten seconds. Thus, when the Novelty-NECS rats were returned to the box on Day 7, there was little or no tendency to explore the niche area, since any memory would be of an 'uninteresting' object in the niche. But the ECS on Day 6 would presumably have the effect of disrupting the memory of the specific nature of the novel object in the niche, which would be more likely to generate exploration around the niche area. This hypothesis is tested in the following experiment.

Experiment 5

The results of Experiment 4 show that a rat finding a novel stimulus in a specific location will explore that location upon re-exposure to the apparatus, but only if given an ECS after the initial discovery of the object. If no ECS is given, the animal shows no tendency to explore the general area. A hypothesis framed to account for these results is based upon the idea that shortly after discovery, the animal classifies the object as non-reinforcing, and thereafter shows no particular interest in exploring it further. If the animal is given an ECS, the memory of the specific nature of the object is lost, and all that remains is the memory of a 'new' object that may or may not be reinforcing-- hence further exploration is seen.

To test this hypothesis, Experiment 5 was designed. The reasoning was that if the animal was removed immediately after the discovery of the object, rather than 10 seconds after, there might not be sufficient time to permit classification of the object as 'uninteresting'. Then upon subsequent exposure to the situation, the animal removed immediately on the previous day would, like the animal given the ECS, show a tendency to explore the general location of the 'new' object. The specific prediction based upon the hypothesis was that animals removed immediately from the apparatus after discovery would show more exploration of the 'niche half' than would no-learning control animals, whereas animals given the standard 10 seconds to explore and classify the new object would not show more exploration than controls on the following day.

Method

Subjects and Apparatus

Subjects were 28 naive, hooded rats weighing 225-250 grams at the start of the experiment. On the day of arrival, animals were housed two to a cage, and were put on a 23 hour deprivation schedule on the following day. Three days later, the experiment began. The apparatus was the same as that used in Experiment 1.

Procedure

The procedure for the first five days was the same as that followed in Experiment 1. On Day 5, animals were divided into three groups, balanced with respect to niche explorations on Days 3, 4, and 5. On Day 6, the Immediate Removal group (n=10) found the novel stimulus (dry water spout) and was removed from the apparatus immediately after insertion of the head into the niche. Two animals were discarded from this group on Day 6 for failing to explore the niche within five minutes. The second group (10-second removal) was given the standard novelty-NECS treatment: the subjects were removed 10 seconds after the exploration of the niche. (As observed in Experiment 4, most of these animals had turned away from the niche by the end of the ten seconds.) The third group (n=9) was given the usual No-Learn No ECS treatment. Two animals had to be discarded from this group for failing to explore the niche within the five minute period on Day 6.

On Day 7, animals were given the regular five minute test exposure to the apparatus, and a record was kept of the position of the animal within the box.

Results

Figure 10 shows that the Novelty-Immediate removal group spent significantly more time in the niche half of the box than the No-Learn control group ($U=10$, $p = .04$), whereas the Novelty-10 second removal group did not ($U=22.5$, n.s.). These results are consistent with the hypothesis that 'Immediate Removal' animals would not have sufficient time to store the memory of the specific details of the novel stimulus, and that the incomplete memory formed in these animals would result in an attraction for the 'niche half' of the apparatus.

General Discussion - Part I

It has been known for some time that, under some conditions, memory is intact after an ECS. Williams (1966), in her review article on the effects of ECS in humans, mentions that in some patients, there are 'islands' or traces of even recent memories that persist. In an earlier study (Williams, 1950), a 'progressive inkblot' technique provides experimental support for this idea. Patients were shown a series of inkblots that began with a completely meaningless design that changed progressively into a clear representation of a familiar object, and were then given an ECS. Afterwards, the patients could name the target object of the series more quickly than patients seeing the series for the first time, although recognition was not immediate.

Complete retention after an ECS has been seen in animal learning (Corson, 1965; Gerbrandt, Buresova, and Bures, 1968), but here the task being learned was a multi-trial discriminated learning task, so possibly the ineffectiveness of the ECS can be attributed to imprecise control over the learning ECS interval. Even in those studies employing the one-trial learning tasks, however, there are some reports of persistence of memory after an ECS.

<u>Memory after ECS: one-trial learning tasks</u>. In general, those reports that have showed persistence of memory after an ECS in a one-trial situation have employed one of four strategies: (a) to test for the return of memory long after learning, (b) to give the animal a 'reminder'

experience (which improves performance relative to that of non-learning animals), (c) to show a savings effect after a second presentation of the learning-experience/ECS combination, and (d) to test for memory at short learn-test intervals.

A frequently-quoted example of the first strategy is Zinkin and Miller (1967). These workers used the basic step-down task, but tested each animal for the presence of avoidance at intervals of 48 and 72 hours after learning, as well as the more usual 24 hours. They found what appeared to be a return of memory-- that is, in the animals receiving FS and ECS, the latencies were progressively higher as the time after learning increased. Their conclusion was that the memory has survived the ECS, although it was in a weakened form, especially when measured at the 24 hour post-learning stage. The phenomenon of 'recovery' shown by these workers was considered by Herz and Peeke (1967); they pointed out that the procedure of Zinkin and Miller might confound a returning memory with the effect of repeated exposure to the apparatus-- the longer latency of the animals might reflect adaptation to the environment rather than memory for the footshock. They argue that the proper test to make is one in which the tests at 48 and 72 hours are done with animals that have not been in the apparatus since learning. And in a later paper, Herz and Peeke (1968) showed that when the animal is tested only at 48 and 72 hours instead of 24 hours, there is no sign of memory, either in appetitive or aversive learning situations. Using two different experimental strategies, King and

Glasser (1970) investigated the return of memory after one-trial passive avoidance followed by an ECS. If the animal was retested only once, no evidence of memory was found as long as four weeks after the learning experience. However, if the learning-ECS animals were repeatedly exposed to the apparatus over a period of weeks, they showed a significant increase in latency. This increase could not be attributed to an habituation effect, since a control group (No-Learn, No ECS) showed no increase in latency over the course of the re-exposure. King and Glasser concluded that some slight trace of the learning experience survives the ECS. It appears that the behavioural manifestation of this slight memory trace depends upon re-exposure to the situation rather than mere passage of time.

The second strategy, that of decreasing the apparent amnesia by giving the animal a 'reminder' shock, has had more consistent success in showing that memory persists. Koppenaal, Jagoda, and Cruce (1967) showed the effectiveness of a mild repetition of the punishing shock in restoring memory in L-ECS animals. The avoidance shown by the Learning-ECS group given the reminder was much greater than that shown by either the NL-ECS-'reminder' animals or by animals given L-ECS, but no reminder. Lewis, Misanin, and Miller (1968) obtained essentially the same results using the step-down design. Before the reminder was administered in this study, the L-ECS animals and NL-ECS animals were similar in their low step-down latency. But after the reminder, the L-ECS animals showed much greater latency than did the NL-ECS animals that were given a 'reminder'. In the Koppenaal, Jagoda, and Cruce study, the reminder shock was an actual repetition of the shock, given while the animal was drinking, but the shock was of a much lower intensity than that used in the original passive avoidance learning. But in the Lewis, Misanin, and Miller study, the 'reminder' shock was given outside the apparatus, and was still capable of in some sense 're-activating' the memory. It is difficult to explain these results if one adheres to the notion that the ECS wipes away all trace of the memory. Clearly the Learn-ECS animals are very different from the NL-ECS animals, even if this difference is only latent before the application of the 'reminder' shock-- certainly the difference between these two groups is obvious after that.

Quartermain, McEwen, and Azmitia (1970), on the basis of experiments that they report, conclude that after the ECS, there is a partly suppressed memory for the learning experience. This suppressed memory lasts for at least four hours, but is gone by 24 hours. If, within these first four hours, there is a re-exposure to the learning situation followed by a non-contingent shock, latency to the step-through (the measure of memory) is significantly improved.

A third strategy has been to depart somewhat from the one-trial learning design, and present a repetition of the learning/ECS treatment. The performance of this group on a subsequent memory test is then examined to see if there has been a savings effect.

Magnus and Lee-Teng (1971), using sub-convulsive currents rather than ECS in newborn chicks conclude that there is no difference in the avoidance performance of chicks given one or two learning/current pairings. The careful design of their study and large numbers in the experimental groups (more than 100) strengthen their conclusion: little if anything remains after electrical stimulation of the brain in these animals.

Opposite results were found in cats by Kesner, McDonough, and Doty (1970). These workers trained their animals to eat at a food dish, then presented an electric shock to the mouth, followed by an ECS. Animals tested after two such experiences showed full avoidance, while cats tested after only one learning/ECS pairing showed complete amnesia. After performing several control experiments to rule out other possible explanations for the data, Kesner et al. conclude that: 'contrary to current concepts of the effects of ECS, some traces of the initial aversive experience have survived to summate with similarly surviving traces of the second aversive experience'.

A fourth successful strategy has been to test for the presence of memory at intervals shorter than the usual 24 hour interval. Geller and Jarvik (1968) showed that when ECS was given 20 seconds after learning, there were still signs of memory (animals took longer than controls to step-through to the punished location) one hour after learning, but the memory had disappeared by 24 hours post-learning.

McGaugh and Landfield (1970) confirmed this result, but showed that if the ECS was given eight seconds after learning rather than 20 seconds after learning, then amnesia was total even one hour after learning. McGaugh and Landfield conclude that the memory seen at one hour is due to the persistence of a short-term memory; and since the short-term memory survived, it clearly cannot be purely electrical in nature. As a possible explanation for the finding that short-term memory can survive the electrical storm from an ECS, they suggest that perhaps the short-term memory may involve a biochemical component. Deutsch (1969) suggests a different explanation for the fading short-term memory found by Geller and Jarvik: ECS does not disrupt memory consolidation but simply accelerates forgetting. Thus the memory is still present one hour later, but by 24 hours post-learning, the animal has forgotten the experience.

These studies have succeeded in showing that something can remain after the administration of an ECS, but almost without exception, the task used has involved footshock and subsequent passive avoidance, usually as a result of a CER. The work of Pinel and Cooper (1966a, 1966b) has shown how an ECS can arrest the development of the 'freezing' response. If one can assume that after an ECS the incipient CER is still present, in a semi-organized state, then it is plausible that a 'reminder' shock, or a repetition of the learning experience can reinstate the incubation process. As Kesner _et al._ said, the second experience would summate with the first.

Some important insight into the 'latent' memory present after an ECS may be provided by two recent studies. Hine and Paolino (1970) and Mendoza and Adams (1969) both present data showing that animals given an aversive learning experience followed by an ECS still show autonomic similarities with the non ECSed animals, even though their overt behaviour demonstrates amnesia. So it is possible that the amnesia is never complete, even when it most seems to be.

Although these studies have a great deal to say about what remains after an ECS interacts with a CER incubation from an aversive learning experience, they have little to tell us about the effects of ECS on memory as defined earlier-- that is, a specific response to a specific stimulus.

Apart from the fact that most of these studies involve the use of passive avoidance tasks, and hence probably confound CER with more specific memory, there is another point of similarity. There seems to be an assumption, usually implicit, to the effect that the memory of an experience is a unitary thing. Thus investigators will speak of a memory being present, or a memory being absent, or a memory being suppressed and recovering. The results of Carlson (1967), Mendoza and Adams (1969), and Hine and Paolino (1970), all showing that an amnesic treatment eliminates some aspects of memory (specific motor responses or cues) while leaving other aspects intact (the emotional or 'affective' component of the experience) show that the assumption of a unitary, 'all or none' memory is inaccurate. Atkinson and Shiffrin (1968) propose that memory, both long-term and short term, is composed of a number of discrete elements, which must be retrieved or co-ordinated in a particular manner for the appropriate behaviour to appear. The results of the present study, as well as those of earlier workers, could be explained by supposing that the ECS can have a disruptive effect on some of the elements of the learning experience, but not on others. Thus, if the behavioural test for memory were based upon elements that were disrupted, the conclusion would be: 'amnesia'. But if the behavioural test tapped elements that had not been disturbed by the ECS, the conclusion would be: 'no amnesia'.

The results obtained in the first five experiments are certainly consistent with the notion that memory of an experience consists of a number of elements, which may or may not survive an amnesic treatment. Specifically, it seems that the animal does not remember the specific nature of the stimulus, but **does** remember the novel stimulus.

Memory for a novel stimulus. Other workers have found that animals do form a memory for a novel stimulus (as in Experiment 4), and that exploration of a novel stimulus declines with continued exposure to the stimulus (as in Experiment 5).

Darchen (1952) has shown that cockroaches will explore a novel stimulus, but during a prolonged exposure to the stimulus, exploration drops. Rats show the same tendency to habituate to a novel stimulus during a continued exposure (Montgomery, 1953, Thompson and Solomon, 1954). In an early paper on this topic, Berlyne (1950) attempted to fit novelty-related behaviour into a Hullian framework by showing that exploration declines and eventually stops in a way that fits a 'drive-satiation' curve. In a later paper, Berlyne (1955), using an apparatus much like that used in the experiments in Part I, gave rats a five minute exposure to an object placed in a niche. Exploration of the niche was higher than that of rats not exposed to the novel object but on the following day, with the object still in the niche, exploration had dropped.

The drop in exploration of a novel stimulus that is typically seen after continued exposure or upon re-exposure shows that the animal remembers the object, or in other words, the novelty has 'worn off'. It is interesting to note that in such a case a lack of behaviour is seen as a sign of memory. These animals thus show a similarity to the animals in Experiments 4 and 5, that discovered the novel stimulus, were given time to explore it, and were then removed without receiving an ECS. That is, the animals from the present experiments remembered that there was something 'uninteresting' in the niche, and showed no particular tendency to explore when returned to the apparatus.

To summarize the findings obtained so far, we can say that an animal suddenly finding a new object in a familiar environment will investigate and classify that object. If the object was reinforcing, then the animal upon return to the situation, shows a marked tendency to explore around the 'reinforced location'; if the object was not reinforcing, no such tendency toward differential exploration is evident.

But if an ECS is given after the discovery of the object, reinforcing or not, then the specific characteristics of the object are lost, and the animal remembers only that 'something new' was in one part of the apparatus on the previous day, and shows a tendency to explore the part of the apparatus that had contained the new object.

That this memory of 'something new' apparently survives an ECS while the memory of water reinforcement does not, was rather surprising. In order to confirm and extend the generality of these findings, the storage of the 'novelty' memory was investigated under different experimental conditions. These experiments are reported in Part II.

PART II

MEMORY FOR A NOVEL STIMULUS AS A FUNCTION OF MOTIVATIONAL STATE AT LEARNING

The results of the experiments of Part I suggest that the memory for a 'novel stimulus' survives the administration of an ECS, even though other characteristics of the object are lost from memory because of the shock. The experiments of Part II investigate the formation of this 'novelty memory' under different sets of experimental conditions.

Experiment 6 replicated the design of Experiment 1 in every particular except that there were fewer groups, and the motivation used was hunger rather than thirst.

Experiment 7 replicated the design of Experiment 1 except that discrimination of the baited location was made more difficult, and a different way of measuring the 'novelty' memory was used.

Experiment 8 was a small study, using only one group, designed to test whether 'novelty' memory could be disrupted if the ECS was given more quickly after the learning experience.

Experiment 9 tested for storage of memory for a novel stimulus under conditions of non-deprivation.

Experiment 6

Method

Subjects and Apparatus

Subjects were 32 naive male, hooded rats weighing 225-250 grams at the start of the experiment. Animals were housed two per cage and on the day following arrival were put on a 23-hour food deprivation schedule. For one hour a day, animals were given access to a small dish containing a paste made of water and crushed purina rat chow. Apparatus was the same as used in previous experiments.

Procedure

The procedure for the first five days was the same as followed in Experiment 1. After Day 5, subjects were divided into four equal groups, balanced on the basis of explorations made during Days 3, 4, and 5: L-NECS, NL-NECS, Novelty ECS, and NL-ECS.

On Day 6, the appropriate treatment was given according to group membership. Three animals were discarded for not exploring the niche within five minutes. The L-NECS group found food reinforcement in the form of a small quantity of the wet food mash received during the days of habituation in the home cages. (Pilot work had shown that dry pellets are unsuitable, as the animal carries them away from the reinforced location, thus making the position memory unreliable.) The Novelty ECS group found a one inch diameter coil of wire in the niche. Day 7 was the same as the habituation trials, and a record was kept of the animal's position using the same method as in Experiment 1.

Results and Discussion

As expected, the L-NECS animals showed (Figure 11) an increased rate of exploration of the niche on Day 7 ($U=0$, $p < .002$) as well as a preference (Figure 12) for the niche half of the box ($U=2$, $p < .002$). The novelty-ECS animals also showed the preference for the niche half of the box ($U=10$, $p < .05$) thus confirming the persistence of the 'novelty' memory under conditions of food deprivation. These results indicate that the novelty effect can be seen under conditions of food deprivation as well as water deprivation.

Experiment 7

In the experiments reported so far, the measure showing the persistence of the novelty memory after an ECS has been the proportion of time spent in the 'niche half' of the apparatus on the day following learning. This measure was taken by the experimenter, watching the animal through one-way glass, and recording the time spent in the niche half with a manually controlled stop watch. Although precautions were taken to avoid biasing the observations on Day 7 (for instance, by randomizing the order in which animals were run), the experiments were not, strictly speaking, blind, since the same experimenter administered the treatment on Day 6 and recorded the critical measures on Day 7. For this reason, it was decided to alter the procedure slightly, to remove any possible influence of the experimenter on the measures of Day 7. This was accomplished by using two niches rather than one—located on opposite walls of the apparatus. With this refinement, the preference measure could be derived from the relative proportion of explorations made to the niche holding the reinforcement, compared to the number made to the non-reinforced niche. Niche explorations were recorded automatically, and the experimenter was entirely outside the room during the measures on Day 7.

The introduction of the second niche altered slightly the character of the learning task as well. Whereas before the reinforced location was relatively easy to discriminate (there was only one wall with a niche), now the animal had to make a slightly more difficult discrimination in order to give evidence of memory for either reinforcement or 'something new'.

Method

Subjects

Subjects were 96 naive, male hooded rats, weighing 225-250 grams at the start of the experiment. Subjects were housed two to a cage upon arrival, and on the following day, were put onto a 23-hour water deprivation schedule. On the third day of the schedule, the experiment began.

Apparatus

Apparatus was the same as that used for Experiments 1 - 6, except that two niches were available for exploration (on opposite walls of the apparatus) throughout the experiment: both niches were fitted with photocell beams connected with counters, so that exploration to each niche would be recorded automatically.

Procedure

Procedure during the first five days was the same for all animals, and was similar to the habituation procedure in Experiment 1. On Day 5, animals were divided into six groups as follows:

Learning-No ECS (15)

Learning-ECS (20)

No Learning - No ECS (20)

No Learning - ECS (20)

Novelty-ECS (10)

Novelty-No ECS (10)

The Day 6 treatment was the same as that employed in Experiment 1, except that the water or the novelty object (dry nozzle) was placed in one of the niches chosen randomly, but groups were balanced with respect to object location on Day 6. Eight animals were discarded on Day 6-- seven failing to explore the niche within five minutes, and one because of a broken spine caused by the seizure.

Position within the box was not recorded on Day 7; instead the position memory was expressed as the percentage of total explorations which were toward the baited niche. For the no-learning groups, one of the niches was arbitrarily designated as the 'target' niche, and the animal was removed 10 seconds after exploring that niche on Day 6. For analysis, the 'target' niche was treated the same way as the 'baited' niche for the other groups, and the position memory was calculated in the same way. It was found in Experiments 1 and 4 that the number of explorations made by a rat on Day 5 occasionally showed a large jump above or below his response level on Days 3 and 4. Since an individual retention score (Day 7 - Day 5) would be quite sensitive to a jump of this kind, it was decided before the start of Experiment 7 that a more reliable and accurate measure of retention would be afforded by comparing the Day 7 exploration level with the average exploration level across days 3, 4 and 5.

Results and Discussion

As shown in Figures 13 and 14, the relationships between the groups are the same as those seen in Experiments 1 and 4. The Learn-No ECS shows memory both in the mean number of responses ($U=28$, $p < .002$) and in the percentage of responses to the reinforced niche, ($U=41$, $p < .002$) compared to its No Learn control group. The Learn-ECS group does not show the increase in mean niche explorations per se compared to its control group, ($U=100$, n.s.) while both the Learn-ECS ($U=50$, $p < .02$) and the Novelty-ECS ($U=30$, $p < .02$) groups show the same tendency to respond more frequently to the niche that contained the reinforcement or novelty object on the day before.

Experiment 8

Experimental findings reported here indicate that when the ECS is given within 10 seconds after learning, memory of the water reinforcement is no longer present, but the memory of the novel stimulus remains. Some workers have found that memory is consolidated very quickly after learning (Chorover and Schiller (1965) found that five seconds is time enough for memory of the step-down task in their experiment), and it is possible that if the ECS were given quickly after learning, even the memory for the novel stimulus would be disrupted.

To test for this possibility, the present experiment was designed.

Method

Subjects and Apparatus

Subjects were 12 hooded male rats, weighing 200-225 grams at the beginning of the experiment. Before the experiment, rats were put under sodium pentathol anaesthesia, and the top of the skull was exposed. Two small brass bolts were inverted, with the heads against the surface of the skull, equidistant between bregma and lambda, centered one-quarter inch from the midline. These bolts were held in place with dental cement. After surgery, the rats were rested for one day, then placed on 23 hour water deprivation. Apparatus was the same as that employed for Experiment 7, with two niches.

Procedure

On the third day of water deprivation, habituation trials began as usual. On day three, wires were fastened to the animals' heads just before their habituation trials, by means of alligator clips which locked onto the threaded end of the bolts. Wires were attached to each animal during the habituation trials on Days 3, 4, 5, and 7.

On Day 6, each rat found water on one of the niches, allowed to drink for 10 seconds, and was then given an ECS, usually while it was still drinking. All subjects showed full tonic-clonic seizures. The subjects were all removed from the apparatus before recovery from the ECS.

The measure taken was that of preference on Day 7, defined (as in Experiment 7) as the proportion of total niche explorations that was made to the reinforced niche.

Results and Discussion

Animal Number	Explorations of Reinforced Niche	Total Explorations
1	1	2
2	1	2
3	2	6
4	4	6
5	5	7
6	2	2

Animal Number	Explorations of Reinforced Niche	Total Explorations
7	3	5
8	3	5
9	3	3
10	7	9
11	2	3
12	1	1
	34	51

For the group, the percentage of explorations that was made to the reinforced niche was 67%. Although there is no control group that received an immediate ECS after No Learning, the figure obtained here compares favorably with results obtained with the L-ECS groups of other experiments, so it is unlikely that even an 'immediate' ECS can disrupt the memory for the novel stimulus.

Experiment 9

In the experiments reported so far, it has been found that during a post-learning test, Novelty-ECS animals show a tendency to remain near the location that was associated with novelty during learning. This effect was seen if the animal was put under food deprivation instead of water deprivation (Experiment 6); under water deprivation in a more difficult discrimination (Experiment 7); when the ECS was given very quickly after learning (Experiment 8). In all of these experiments a common element was motivation created by food or water deprivation. In the present experiment, animals were non-deprived at the time of learning: this was done to assess the importance of motivation for the storage of 'memory for a novel stimulus'.

In order to enhance any tendency to remain in the niche area on Day 7, rats were 23-hours water-deprived at the time of the Day 7 test session. Some reports in the literature (these will be discussed at a later point) suggested that the memory for a novel stimulus has a more potent effect on behaviour if the animal is in a state of deprivation during testing.

Method

Subjects and Apparatus

Subjects were 16 naive male, hooded rats 225-250 grams at the beginning of the experiment. These animals were not put on a deprivation schedule after arrival: they were housed two to a cage and given food and water ad lib. On the fourth day after arrival, the experiment began. Apparatus was the same as used previously.

Procedure

The procedure was the same as that followed previously. On Day 5, subjects were divided into two groups, balanced with respect to niche explorations on Days 3, 4 and 5. On Day 6, one group found the novel stimulus and was removed after 10 seconds and given an ECS. The other animals were removed 10 seconds after the first niche exploration and given an ECS. Two animals were discarded on Day 6— one for not responding and one suffered a broken spine as a result of the ECS. All animals were put on water deprivation one hour after learning, and were given the standard five minute test session on Day 7. The measure taken was time spent in niche half on Day 7.

Results and Discussion

Figure 15 illustrates the result of the experiment: there is no difference between the two groups ($U=20$, $p > .60$). In this experiment, then, the Novelty-ECS animals show no sign of memory for the novel stimulus. This result is in contrast with the previous reported experiments, in all of which Novelty-ECS animals showed a significant tendency to occupy the niche half, compared with the NL-ECS control group. The implications of this finding will be discussed more fully in the general discussion of Part II.

General Discussion - Part II

Experiments 6 and 7 confirm the hypothesis that memory for a novel stimulus is stored and resists disruption by an ECS. Furthermore, Experiment 8 rules out the possibility that the effect of ECS on the memory of the learning experiment can be accounted for by a delay in the administration of the ECS: it appears that the memory for the novel stimulus is formed almost immediately. And the results of Experiment 9 suggest that the appearance of the memory for the novel stimulus after an ECS depends upon the motivational state of the animal at the time of learning.

Effects of Motivational State on Exploratory Behaviour

The evidence relevant to the question of whether a high level of drive (food or water deprivation) increases or potentiates exploration is somewhat conflicting. One early approach to the problem was to allow either deprived or satiated rats to bar-press, with no reward other than the onset of a small light (appearance of a novel stimulus). Using this approach, Hurwitz and De (1958) found no difference between deprived and satiated rats, Davis (1958) found that food-deprived rats pressed more, and Forgays and Levin (1958) reported that food-deprived rats bar-press more, but their data do not show a statistically reliable difference. Another technique has been to observe perambulation in a maze, again comparing deprived rats with satiated animals. Thompson (1953), Montgomery (1953), and Zimbardo and Montgomery (1957) all found that there was either no difference, or that the satiated rats actually showed more, rather than less exploration, but Zimbardo and Miller (1958) pointed out that interpretation of these studies is difficult, because increased exploration might manifest itself as an increased tendency to explore the immediate surroundings, which would result in less rather than more movement within the maze. By keeping a rat confined within an area till it was presumably well explored, then permitting access to a new environment, they found that the satiated animals took longer to enter the new milieu, thus showing less exploration.

Using a sensitive microswitch to register the movements of an animal within a cage, Campbell and Sheffield (1953) found that hungry animals showed greater reaction to the sudden introduction of a novel object than did satiated animals. Both animals showed an increase in activity, but the increase in the hungry animals was greater.

Work with humans has shown that increasing motivation at the time of learning increases accuracy of memory at the time of recall (Heinrich, 1968; Loftus and Wickens, 1970; Weiner and Walker, 1966). The results of Heinrich are a close parallel of those obtained in Experiments 4 and 9: if motivation was high at learning and high at recall, then performance was very good (Experiment 4); but if motivation was low at learning and high at recall, performance was not as good (Experiment 9).

Thus on the whole, there is some reason to think that at least under some conditions animals in a state of deprivation are more reactive to a novel stimulus than are satiated animals. The results of Experiment 9 suggest that this difference is related to memory storage.

In Experiment 9 it was found that animals finding the novel stimulus and then given an ECS show no sign of memory for the novel stimulus on the following day. The two most plausible explanations for this finding are: (a) the memory for the novel stimulus was never stored in the first place, and (b) the memory was stored, but because of the lack of motivation (or relatively low level of activation or excitement) the memory was not 'fixed' strongly and the ECS was able to disrupt it.

The first possibility, that the memory was never stored, would be consistent with some recent ideas relating motivation and behaviour. Bindra and Palfai (1967) propose that the organismic state of the animal (including drive level) interacts with an incentive object in the environment to create what they call a 'central motive state' (CMS). It is this CMS that in turn directs the appropriate behaviour. Without both of the constituent ingredients of the CMS, the behaviour is not organized. And if one can assume that another of the functions of the CMS is the organization of situation-specific memory, then it would follow that without the deprivation state, memory is not stored for the situation.

The second explanation for the results of Experiment 9, that the memory was stored, but in such a weakened form that the ECS was able to disrupt it, might seem the more likely one. This is because in a study by Berlyne (1955) rats that were non-deprived (as in Experiment 9 here) were able to show that they remembered a novel stimulus encountered on the previous day-- the memory being manifested as a decrease in exploration of the novel object. However, in the Berlyne study, the rats were exposed to the novel object for three minutes, as compared with 10 seconds for the animals in Experiment 9, and it is not certain that 10 seconds is long enough to permit storage of the memory.

A more precise idea of how the motivational state might be related to memory is suggested by the ideas of Livingston (1967). He proposed that the registration of items in memory is mediated by the level of arousal of the animal at the time of exposure: if arousal is high enough, then the details of the ongoing situation are 'printed' in the memory. Some experimental support for this idea can be found in the work of Barondes and Cohen (1968). Using a protein synthesis inhibitor to disrupt memory of a passive avoidance task, these workers found that short-term memory for the task persisted some three hours after the introduction of the inhibitor, and that a sudden increase in the arousal level of the animal during this time, either by electric shock or by chemical stimulants, could result in the printing of the information into long-term memory; however, without the arousal, the information would be lost. Applying these ideas to the results of Experiment 9, we could say that the discovery of a novel stimulus is more arousing for an animal which has been deprived of food or water than it is for a satiated animal. Therefore, the memory for the experience will be much more strongly 'printed' into long term storage for the deprived animal. In the satiated animal, on the other hand, the relative lack of arousal following the discovery of the novel object would mean either that the information about the object did not enter storage, or was not printed strongly enough to withstand the ECS.

Concluding Discussion

Before drawing any final conclusions from the nine studies reported here, two aspects of the results should be given some critical attention. Looking first at 'time spent in the niche half' (Experiments 1, 6, and 9) the measure showing the presence of memory even after ECS, there is a consistent tendency for the NL-ECS group to spend less time in the niche half of the box on the day after the ECS. Although this tendency was never statistically significant in any one experiment, a significant difference is evident if one compares the preference of all the NL-ECS groups with that of all the NL-NECS groups. One would expect, by chance, a mean of 2.5 minutes on this measure, that is, exactly half of the time should be spent in the 'niche half'. The NL-NECS groups (21 animals) together spent 2:35, whereas the NL-ECS groups (21 animals) spent 2:14. This difference is significant with a probability of less than .05 (Mann-Whitney U=130).

The avoidance shown by the NL-ECS groups for the niche half of the box might be due to a slight aversiveness of the ECS. This would be consistent with reports that have shown a slight aversiveness after a single ECS (Lewis, Miller, and Misanin, 1968). However, even if a single ECS does produce aversiveness in this situation, it must be stressed that this explanation cannot account for the behavioural deficit shown by the L-ECS rats on the other measure of memory, the 'head-poke' frequency. The results of Experiment 3 show that pairing the response with the ECS does not result in response suppression if this pairing takes place after original learning, hence some other explanation is necessary and the most obvious is that there has been an amnesia for the experience of the reinforcement.

The 'aversiveness' shown by the NL-ECS rats may, however, be artifactual. In a paper exploring the post-shock long term effects of a single ECS, Aron, Glick, and Jarvik (1969) report that among other things, administration of ECS results in a heightened sensitivity to light that lasts several days. Thus, if there were an unequal distribution of light in the apparatus on Day 7, it would be reasonable to suppose that the animals that had received an ECS on the day previous would tend to prefer those parts of the apparatus that were comparatively less illuminated. Most of the apparatus was illuminated by the 6 watt bulb located in the middle of the lid, so there is no reason to expect an unequal distribution from this source, but the niche was fitted with a small (2.2 watt) bulb that activated the photocell counter circuit. The arrangement of the bulb was such that the beam of light would be directed into the animal's eye during exploration of the niche. Therefore, the light beam might have become a slightly punishing stimulus for the ECSed rats on Day 7, possibly accounting for their avoidance of the niche half of the box.

Presumably the same negative influence (either ECS-induced aversiveness, or light sensitivity, or both) was operating on the L-ECS and on the Novelty-ECS rats, but these animals showed, in every experiment, significantly more time spent in the niche half than did the NL-ECS control. In fact, if the measures from all the L-ECS animals are combined, and those from all the Novelty-ECS animals are combined, and each of these larger groups is then compared with the 'chance' level of 2.5 minutes, a binomial test shows that each of these groups spends significantly more time on the niche half ($p < .002$ for each group). Clearly, then the main experimental finding of an increased attraction for the niche half of the box on the part of the L-ECS and Novelty-ECS animals, cannot be explained away as only an artifact of the depressed preference shown by the NL-ECS animals.

A second general aspect of the results that deserves consideration concerns the 'frequency of niche exploration' measure, the measure that corresponds to that used in previous studies employing one-trial appetitive learning. In each of the studies reported here, the L-ECS group showed a total amnesia, as defined earlier-- that is, fewer explorations than the group that learned with no ECS, and no more explorations than the group that did not learn and got an ECS. But in each of these experiments, the L-ECS group showed a tendency to explore more than the NL-ECS group, although this was never significant. Examination of the data presented by others shows the same thing: the L-ECS group is always higher than the NL-ECS group, but not significantly so. In fact, Pinel (1969), in one of his experiments, obtains only a partial amnesia in his L-ECS rats, because the difference between the L-ECS and the NL-ECS is significantly large. Such a consistent difference, small though it is, may be of some importance in helping to understand an important aspect of the ECS effect. With this in mind, we can turn to the interpretations and theoretical implications of the data.

The discussion of the data has been organized into three levels. First, there is the level of the data itself, and in particular, the finding of an apparent memory loss on one measure of memory (although there is a suggestion of very slight retention even on the measure showing amnesia).

The second level is that of explanation for the empirical results. Three distinct explanations for the results are proposed, each of them postulating rather different effects of the ECS upon inferred memory events. The discussion at this level will include such possible ECS effects as: interference with retrieval, loss of memory items, effects upon rate of consolidation.

The third and last level of discussion is that of the most general theoretical conceptions of the nature of memory organization.

Following a brief description of the general theoretical issues, each of three proposed explanations for the data will be considered in some detail, with attention paid to (a) in what way and how well the explanation can account for the empirical results, and (b) the implications that the explanation, if true, would hold with regard to the more general theoretical issues.

General Overviews of Memory

Single system. It is conceivable that the learning experience is stored in memory in one coherent 'package'— that is, all the details of the experience, such as the nature of the stimulus, its location, and the motor response required to 'get at' it, are packed into one large memory trace, by one memory system. This complex trace could be of varying degrees of strength. If the trace is strong, then performance will be accurate and reliable; if the trace is weak, performance will show deficits, or may not reflect the memory at all. By this broad view of the nature of memory, the ECS can have the effect of weakening the trace, and if the trace is weakened enough then 'amnesia' results.

Multi-system. By contrast, one could suppose that memory is not stored in one large trace, by one large system, but that instead several different physical systems store traces of different aspects of the learning experience. (These systems need not be physically separate in the brain— in fact, it seems unlikely that each category of memory has its own private brain structure. Some evidence (to be discussed later) from John's laboratory suggest that widespread brain regions may be involved in the processing of a memory.)

Explanations of the ECS Effect

Possibility 1. All the elements of the learning experience are present in memory, but the ECS has introduced a distortion that affects some performance measures more than others.

Possibility 2. Although the specific nature of the reinforcement is lost, the animal does remember that 'something good' was in the niche, which thus has a positive 'valence' and attracts the animal during testing.

Possibility 3. Only the memory for the novel stimulus survives and there is no remnant of the specific details, nor is there any 'affective' association with the niche.

According to the first suggested explanation, the ECS has not erased anything from the memory store, but has simply weakened the trace or prevented access to the stored information. This alternative was proposed by Weiskrantz (1966) in its general form: the notion was that the ECS increased the background 'noise' in the central nervous system, thereby decreasing the clarity of the memory or 'signal' that was the target of the memory search. Sometimes the ECS-induced noise would later subside enough to permit retrival of the information-- this would correspond to the return of memory in patients that receive ECS in the course of therapy. The idea of distortion finds support in some very recent work done in Meyer's lab (Robbins and Meyer, 1970, Howard and Meyer, 1971). Using multiple-trial discrimination learning, these workers trained rats in a series of problems as follows: F_1, S_2, F_3, where the first and third problems were learned for a food reward, and the second was learned for shock avoidance. If the animal was given an ECS immediately after acquiring problem 3, then subsequent testing showed a partial amnesia for problem 1, but no effect on problem 2, which was learned under a different motivation. The same effect was obtained if the first and third problems were for shock avoidance and the second was for food reward. The authors claimed to show a retrograde amnesia effect that was a function of motivational conditions, but an additional possible explanation of their results would involve a 'scrambling' of information that was located in one particular channel, the channel being determined, to a great extent, by the motivational condition at the time of learning. These results are consistent with the idea that the ECS 'scrambles' or otherwise distorts information in the central nervous system.

In their 1971 review paper, McGaugh and Dawson suggest a model of ECS action that differs slightly from that of Weiskrantz (1966), although both models seem to share the assumption that all the elements of memory survive the ECS. In the McGaugh and Dawson version, the ECS has the effect of diminishing the strength of the memory 'signal' rather than increasing the level of the background 'noise'. More specifically, they propose that the strength of the long-term memory trace is a direct function of the duration of the short term memory trace, and that the ECS has the function of accelerating the decay of the short-term memory trace.

If this first explanation is in fact correct, that is if all the memory survives the ECS but in a weakened or scrambled form, then the omnibus trace theory of memory organization runs into difficulties. One would predict that a weakened omnibus trace would result in performance decrements across all behavioural measures. The results are otherwise: the measure linked with the novelty element of memory is affected much less by the ECS than is the measure linked with the 'reinforcement' element of memory.

One can imagine a kind of selective blocking imposed upon the omnibus trace by the ECS, with the result that certain parts of that trace are not open to retrieval. But this is a rather clumsy mechanism. Besides, such a selective blocking of function pre-supposes a high degree of autonomy for each of the parts of the omnibus trace. If this degree of autonomy is postulated, so that each part of the omnibus trace has an independent link with some kind of behavioural output, then the 'omnibus trace' becomes only a fiction: one has infact a set of memory systems.

How plausible is the notion of complete retention after an ECS, if one accepts the multi-systems overview of memory? By this interpretation, the ECS has weakened one of the systems of memory in a selective way, but the information is still present in that system. Such an interpretation would fit well with the results of several studies in which ECS has been given at various intervals after learning: it has been found that a partial memory remains, whose strength is a direct function of the learning-ECS interval. It could well be that at the short intervals used in the present studies, the slight tendency of the L-ECS animals to explore the niche more than do NL-ECS animals represents the lower limit of the partial memory for the water reinforcement. (Using the passive-avoidance task, Lewis, Misanin, and Miller (1969) present evidence suggesting that under some conditions, some degree of long-term memory is formed even when the ECS is given one-half second after learning.) On the other hand, alternative explanations are possible, and should be examined carefully before we accept too quickly the notion that ECS functions only to distort or weaken memories, never to disrupt them.

A second general explanation for the results is based on the assumption that the specific details of the learning experience have been lost, and that the animal remembers only that 'something good' was in the niche. This hypothesis is consistent with a great deal of the work done with aversive learning, showing that some kind of 'fear' survived the amnesic treatment, although more specific details of the learning experience did not (Carlson, 1967, Hine and Paoline, 1970). If an unpleasant experience can result in location specific aversiveness surviving an ECS, it is certainly possible that a pleasant experience can result in an attraction being associated with a location. Furthermore, it is not hard to imagine how an attraction of the sort used in the present studies, even if slight (there was only one learning experience), could result in a tendency to gravitate toward the 'reinforced location' and explore the niche slightly more than a non-reinforced rat would. The survival of this 'affective' aspect of the learning experience may be reflected in the tendency of the L-ECS group to explore slightly more than the NL-ECS group.

If this interpretation is correct and the cues of the niche do trigger an affectively based attraction for the niche, then it might be expected that this affective reaction would be reflected in autonomic measures. In their review paper, Malmo and Belanger (1967) discuss the question of arousal generated by environmental cues associated with reinforcement, and cite work showing that under some conditions the environmental cues can affect the heart rate of the animal. With this work in mind the author investigated the heart rate of the animals experiencing one-trial learning for a water reward. The objective of the pilot experiment was to see whether (a) heart rate would change in the animals finding water, not given an ECS, and returned to the apparatus on the following day (presumably because of the association of the niche cues with the water triggering an affective reaction); and (b) to see whether the heart rate would change in the same way for the animals finding the water and then getting an ECS. If the ECS did not disrupt the heart rate change, then there would be some support for the idea that the 'affective' component of the learning experience had survived and could explain the slight tendency of the L-ECS animals to explore the niche.

Unfortunately, the results of the pilot experiment failed to show any reliable effect of the learning experience upon heart rate, even when ECS was not given. This might be explained by the small numbers in each group (7 and 6). Or perhaps the heart-rate changes seen by other workers occur only when there have been very many pairings of the situational cues with the reinforcement-- this suggestion will be examined in more detail at a later point.

Although the pilot experiment failed to show the hoped-for heart rate changes, one cannot justifiably reject the possibility that 'affective' memory survives the ECS. Perhaps the heart rate is an inappropriate index of 'affective' memory in this situation. But the second proposed explanation for the data contains two propositions: that the 'affective' component is formed and survives the ECS, and that the memory of water reinforcement _per se_ is lost. If the notion that the affect survives is still plausible in spite of the results of the pilot experiment, what can be said for the idea that there is a definite loss of one of the elements of the experience? There is a certain risk in asserting that something is _absent_, since there are logical difficulties in proving a negative fact: failure to find something in a given category of memory may only mean that you have not looked hard enough. Possibly the memory for water reinforcement has been rendered irretrieveable rather than lost, as postulated by the first suggested explanation. On the basis of the evidence available at present, both of the explanations offered so far are possible.

The third general explanation for the results goes even further than the second in supposing that there is a definite loss from memory after the ECS. That is, not only the specific details of water reinforcement, but also the 'affective' component of the experience is lost, and nothing remains but the memory for the novel experience. From this hypothesis, one would predict that there should be no difference between the L-ECS group and the Novelty-ECS group on the niche-exploration measure, since in both groups there is only the memory for 'something new' in the niche and nothing more to influence behaviour. Applying the usual analysis to this performance measure, we see that this is true--

both groups show significantly less exploration than the Learn-No ECS group, and no more exploration than the No-Learn, ECS group. The interpretation made of this previously has been one of 'amnesia' in the L-ECS group, and 'no learning' in the novelty-ECS group. But is there any difference between the L-ECS and the Novelty-ECS group? It can be argued that this is the important comparison to make if one is interested in knowing whether any memory other than 'novelty' is present in the Learning-ECS group. In surveying the results as a whole, we can see that there is a tendency, usually slight, for the L-ECS group to explore the niche more than does the Novelty-ECS group. And in Experiment 7, this difference is statistically significant.

The strong suggestion of a genuine difference between these two groups can be expected if either of the first two explanations is true, but raises problems for the third explanation, which assumes that both of these groups retain only the 'novelty' memory. But it may be possible to explain this slightly higher exploration of the L-ECS group without resorting to the notion that some aspect of reinforcement has survived the ECS. There is some evidence (Norman, 1966, Massaro, 1970) that accuracy in memory is a function of the amount of 'perceptual processing' performed by the subject. The more time the subject spends looking at, or otherwise attending to the material, the more accurate memory will be. This idea could be applied, not implausibly, to the present experimental results. It has already been noted that the animals finding water tend to spend all of their time (10 seconds post-discovery) drinking, whereas the animals finding the novel stimulus usually have moved away from the niche entirely by the end of the 10 seconds. Clearly, the animals that are drinking for the entire ten seconds are doing more 'perceptual processing' than those rats that simply sniff and walk away. Thus, on the day following learning, the L-ECS animals might simply have a stronger 'novelty memory' than the Novelty-ECS rats.

The second and third proposed explanations share the assumption that there has been definite loss from memory, and as such they both fit readily the idea that the overall organization of memory is in the form of a set of memory systems. In both cases, the behavioural deficit results from the loss of information from one of the systems: in the second proposed explanation, the novelty memory and the 'affective' element is left behind; in the third explanation, only the novelty memory is left behind. In the discussion of the first proposed explanation (the ECS effect is one of interference), it was argued that acceptance of this explanation involved the rejection of the omnibus trace theory, on the grounds that a selective blocking of a monolithic trace was an improbably clumsy mechanism. Acceptance of the second or third explanations, however, does not lead to the same rejection of the omnibus trace theory. The loss of part of the omnibus trace is not attributed to a selective destruction of part of an already-formed memory-- that would be open to the same objections raised against selective interference with access. A more plausible idea is that the ECS has the effect of blocking the synthesis of the 'omnibus trace' before that synthesis is completed. If one can make the assumption that some parts of the omnibus trace (perhaps those coding the more detailed information) take longer to become permanently set, then it becomes possible to see how an incomplete trace could result after an ECS. This idea is closely related to the theoretical notion of Dawson and McGaugh-- one could interpret their idea that the duration of the short-term memory determined the extent of consolidation of long-term memory as meaning that the ECS can halt the consolidation process at some incomplete point.

Of course, this notion of ECS stopping the consolidation process could be applied with equal plausibility to the multi-systems theory. Thus, the ECS stops all ongoing consolidation, and those systems that have finished their consolidating will not be affected while those systems still consolidating will contain an incomplete, ineffective trace after the ECS.

To summarize the discussion so far, two general overviews of memory organization have been suggested, and three possible explanatory hypotheses for the experimental results have been considered. Arguments have been advanced to establish the ability of each of these three hypotheses to plausibly explain the data. On the strength of the experimental results reported, it is not possible to choose the correct explanatory hypothesis: it is apparent that further work is required. As for the more general theoretical notions, the final answer is even more remote, although the correct explanation of these experimental results would constitute an important advance toward that kind of comprehensive understanding: clearly investigation of a memory trace (omnibus or multiple) would be considerably facilitated if one knew the nature and number of memory categories formed after learning, and disrupted after an ECS.

Future Research

Progress in the resolution of these issues will likely depend upon how successful investigators are in reaching a high level of precision in two chief areas. First, there must be precise control over the kind of memory that is being formed in the experimental situation. To a limited extent, as was demonstrated in this thesis, this kind of precision can be approached by careful experimental design-- the inclusion of the appropriate control groups permitted the separation of 'memory for a novel stimulus' from 'memory for reinforcement'.

There are limits to the progress that can be made by employing purely behavioural techniques. For the reasons discussed earlier, it is impossible to conclude, from observation of a behavioural deficit, that there has been an absolute loss of an element from memory. Similarly, a behavioural demonstration of some degree of retention after an ECS does not prove that all components of the memory have survived. It is the author's opinion that a definitive answer to these questions will depend upon considerable advances in identifying the physiological correlates of learning, and this is the second area in which greater precision is needed-- in identifying the brain structures, and the events within those structures, that correspond to specific memory events.

<u>Studies of specific brain areas and memory</u>. Useful as the ECS has been in previous studies, it is not an appropriate technique to use if one hopes to gain specific information about the specific structures that might be involved in memory, since the current passes through so many brain areas (Lorimer, Segal, and Stein, 1949). (Furthermore, some evidence exists that the effectiveness of an ECS depends upon the particular route that the current takes through the brain (Dorfman and Jarvik, 1968, Ray and Barrett, 1969).) Clearly, interventions that are limited in their effect are necessary for making inferences about limited brain areas.

Some progress has already been made on the difficult problem of identifying the structures involved with storage of information in memory. For instance, by electrically stimulating the amygdala after learning, some workers (Kesner and Doty, 1968, McDonough and Kesner, 1971, and McIntyre, 1970) have been able to show that normal activity in that structure after learning is important for the proper storage of a 'passive avoidance' task. Glickman (1958) showed that normal storage of memory for a passive avoidance task also required coherent activity in the ascending reticular formation after learning.

Because of the work of Milner (1966) showing dramatic and clear memory deficits following lesions to the hippocampal area in humans, many investigators have been attracted to that particular brain structure and have attempted to show an analogous importance for the hippocampus in animal memory. A typical strategy has been to use a modification of the potassium chloride spreading depression technique, limiting the effective application of the KCl to the hippocampus. Using this technique, Avis and Carlton (1968) were able to show that an apparent amnesia resulted, and that the degree of amnesia was a direct function of the extent of hippocampal EEG suppression. A second general strategy has involved the use of lesions to the hippocampal area, in an attempt to duplicate the effect that such lesions have in humans. Although there has been some success in showing the involvement of the hippocampal region in short-term memory (for instance, Uretsky and McCleary, 1969) the experimental results of Kimble (1963) argue against any simple interpretation of the performance deficits seen in animals with lesions in the hippocampal region. In particular, one of the experiments he reports shows no deficit whatever in the acquisition of a discrimination task by hippocampally lesioned rats; a result that is hard to reconcile with a presumed short-term memory deficit in these animals.

There are a number of difficulties involved in the interpretation of studies that employ electrical stimulation or lesioning of specific structures in the brain. Some of these problems stem from conflicts in the results reported by different workers, but others are inherent in the method itself. For example, although Glickman (1958) found that stimulation of the ascending reticular formation after learning resulted in amnesia, workers in Bloch's laboratory have apparently found an opposite result: using one-trial learning in an appetitive situation, they found that stimulation of the reticular formation after learning increased the resistance of the memory to disruption by an anesthetic amnesic agent (Bloch and Deweer, 1968, Lecomte, Deweer, and Bloch, 1969). (This particular discrepancy may perhaps be explained by the fact that Lecomte et al. used positive reinforcement, whereas Glickman's task was shock avoidance. There were also some differences in the timing and duration of the stimulation, and Ojemann, Blick, and Ward (1971) have shown that, depending upon the time when the stimulation was given, accuracy of recall from the memory in humans was either diminished, or even improved.) Another typical example of discrepant results can be seen in Hostetter's (1968) paper on hippocampal lesions in rats. Although lesions to the hippocampal area have sometimes been associated with deficits in short-term memory, Hostetter has found that these lesions actually diminish the effectiveness of an ECS as an amnesic agent.

Two recent studies employing the technique of hippocampal spreading depression provide a clear illustration of the persistent problem of identifying a memory deficit as 'amnesia' as opposed to 'interference with retrieval'. Hughes (1969) found that application of hippocampal spreading depression one day after learning caused amnesia when the retention test was given five days after learning, but if the retention test was given 21 days after learning, memory had partially returned. In a later paper, Kapp and Schneider (1971) argue that the effect of KCl on one day old memories (as in the Hughes study) is an effect on access to an already-stored memory, since the memory can return. But, they argue, if the spreading depression is applied immediately after learning, the effect is a permanent disruption of memory, as evidenced by the fact that the memory does not return. But it is certainly plausible to argue that even in the case of the more immediate application of the amnesic agent, the memory has been in fact permanently stored, and that the failure of the memory to reappear during the learn-test interval is due to a rather more severe interference with access to the memory, rather than any 'permanent disruption' of the trace. The plausibility of both of these interpretations calls to mind the analogous difficulty encountered in trying to determine whether, in the experiments reported in this thesis, memory for the water reinforcement has been actually lost from storage, or whether there was only an interference or weakening of that memory. The general point that can be drawn from these considerations is that following any amnesic treatment (general or structure-specific), a behavioural deficit cannot be interpreted unambiguously as loss of an item from the memory store.

On the other hand, it cannot be concluded, from the failure of a given experimental treatment to result in behavioural amnesia, that the structure in question has nothing to do with memory storage processes. As an example, the ability of an animal to store some memories perfectly well after bilateral lesion of the hippocampus (Kimble, 1963) does not mean that in the normal animal, the hippocampal region is not involved with memory. The phenomenon of 'compensation' is commonplace in clinical observation, and it is possible that after surgery other brain regions have taken over the memory functions normally performed by the hippocampus.

A somewhat cynical rendering of these arguments might be that, whatever the behavioural effect of any specific lesion, nothing whatever can be concluded regarding the role of that structure in memory function. Certainly, it is difficult indeed to see how these structure-specific techniques will be able to provide answers to the questions that have been raised by the experiments reported in this thesis. It is the author's opinion that a more profitable approach to these questions involves the observation of brain function in the intact animal, during the course of memory storage, in an attempt to identify the structures, and the patterns of brain activity, that might be involved.

Examination of ongoing brain activity. In recent years there have been encouraging signs of progress in this direction. In his review article, Adey (1967) discusses a good deal of the work he has done on the EEG and impedance changes he has observed during alerting, and discrimination. A particularly intriguing finding has been the shift in activity in the hippocampus of the cat that parallels the behavioural shift from normal 'alert' conditions to making a discrimination for a food reward. Sparks and Travis (1968) examined single units in the reticular formation and their activity during the performance of a discrimination task for a food reward, and found that some units showed a systematic shift in activity following the appearance of a cue that had been associated with the reward. In a series of papers, John has investigated the neuronal activity in various regions of the brain during ongoing behaviour (John and Mcrgades, 1969a, John and Morgades, 1969b, John, Shimokochi, and Bartlett, 1969). Some of the findings from these studies show that a given behavioural response is keyed to a specific pattern of activity that precedes the onset of the response; that it is possible to predict the response by observing the activity; that the particular pattern of activity that corresponds to the response is present in 'widely distributed' regions of the brain. Spinelli and Pribram (1970), using monkeys in a visual discrimination task for a food reward, examined the activity of neurons in the visual cortex before, during, and after acquisition of the task. They found that the pattern of activity seen during presentation of the stimuli did not change during the course of learning, regardless of whether the response was correct or incorrect. However, neural activity seen during the behavioural responses became increasingly correlated as learning progressed, with the particular type of response that was to be made being accompanied by a distinct pattern of neural activity. This finding is reminiscent of some earlier work of John, showing that the specific pattern seen during presentation of a CS becomes more and more coherent as training progresses (see John, 1967, for a review of this work).

Spinelli and Pribram (1970) were not successful in showing any general changes, other than the response related changes, in the pattern of neuronal firing as a visual stimulus became more meaningful. However, Burns and Webb (1970) were able to do so using cats. The animals were first trained in a food-approach/shock avoidance task, in which different patterns were assoicated with food and shock. Following acquisition to a criterion of accurate performance, the animals were anesthetized and the activity of single units outside the primary visual cortex was examined. It was found that these units showed much more activity in response to 'meaningful' patterns-- that is, patterns that had either meant 'food here' or else 'go-away or you will get shock'. Patterns which evoked the same degree of activity in the visual cortex of naive animals, but which were 'meaningless' to the experimental animals, tended to evoke much less response in the neurons studied outside the visual cortex. This result is consistent with the work of John cited earlier, showing that the particular pattern of activity assoicated with a response is present in widespread regions in those animals that have been well-trained.

It is possible that the work of Burns can provide an explanation for the failure of the pilot experiment in heart-rate changes that was mentioned earlier. In that experiment, the objective was to train rats in one trial to expect water in a certain specific location, then to look for changes in the heart rate (presumably reflecting a change in arousal) when the thirsty rat was again given a chance to go back to the reinforced location subsequent to learning. The failure to see reliable changes in heart rate, even in those rats that did not receive an ECS, can perhaps be attributed to a failure of the neural representation of that water memory to spread to those regions of the brain whose activity would influence autonomic measures such as heart rate.

Conclusion

The major finding of the experiments reported in this thesis is that memory for a novel stimulus and memory for water reinforcement are both stored after the one-trial learning experience, and that these memories are affected very differently by an ECS. But an unsolved issue has been the precise nature of the ECS effect. It appears that the ECS does not particularly affect the memory for the novel stimulus, while it either distorts, seriously weakens, or completely disrupts the memory for water *per se*. In addition, the question of the persistence of any affective 'color' to the experimental situation, as a result of the positive reinforcement, is left unsolved. Arguments were advanced in the discussion section against the usefulness of general disruption of neural activity and of structure-specific disruption as strategies for answering the questions posed by the data reported here.

It seems that the examination of ongoing brain activity described in the final section of this discussion has more promise as a general strategy. If it could be shown, for example, that the memory for water is represented by a certain specific pattern of neural activity, in the same way that John has shown that performance of a specific response involves the presence of a certain specific neural activity, then we would be much closer to an accurate understanding of what remains after an ECS.

Whatever the answer to this question of the status of the 'water memory' after an ECS, it is clear that this aspect of the animal's experience is affected much more drastically than is the memory for the novel stimulus. A possible implication of this finding is that there are at least two systems engaged in putting information into long-term memory storage. One of these systems would be responsible for handling relatively crude aspects of the learning experience, such as novelty in a particular place. This kind of information would have high priority for an animal in the wild, and could have some connection with the primitive orienting response. The second system would be involved with the specific details of the object (which would be of relatively low priority in the event that the object is classified as non-threatening, or 'uninteresting').

There is an interesting parallel between the two-part hypothesis presented here and some recent work done on perception, suggesting that there are two visual systems (Gibson, 1970, Schneider, 1969). Schneider characterized one system as concerned with the cruder aspects of perception, such as the animal's location relative to various objects, and the other system as concerned with the finer details of perception. His data show that some lesions will affect one system without influencing the other, thus giving anatomical support to his hypothesis.

It is interesting to speculate on a set of ideas by which Schneider's perceptual ideas could be linked with the ideas presented in this thesis. Quite possibly, the distinction made between 'perception' and 'memory' is arbitrary and misleading at the physiological level, and these processes are to a great extent based upon the same mechanisms. (For example, it might be the case that different categories of information might be dealt with by different perceptual-memory systems in the brain.) If this were true, it would follow that some memories would be quite different from others, depending on the nature of the mechanisms handling the information entering storage. Thus for instance, memories stored by one kind of perceptual-memory system would be vulnerable to disruption by a given experimental treatment, whereas other perceptual-memory systems would produce more resilient memories.

If these ideas regarding the intimate relations between perception and memory, and separable perceptual-memory systems, are true it would mean that some basic *a priori* notions about the categories of mental function (perception here, memory there, etc.) would have to be revised. Future experimental study, involving memory disruption as a function of sensory modality, and careful analysis of ongoing neuronal activity during perception and recall should prove helpful in determining the degree of overlap between 'perception' and 'memory'. Certainly, the results of the present thesis show that in these future investigations, great care must be taken to separate storage of a non-detailed 'novelty' memory from storage of a detailed memory of the learning experience.

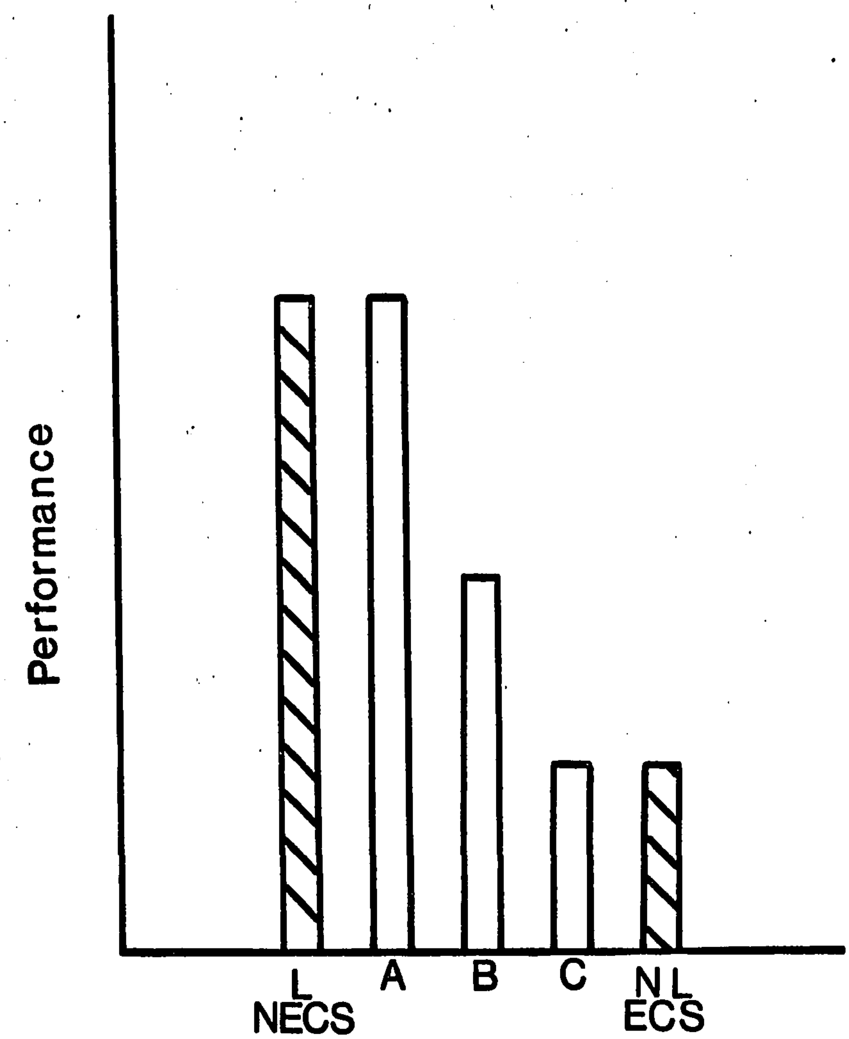

Figure 1. Statistical relationships by which memory and amnesia are inferred. Group A demonstrates complete retention; Group C shows complete amnesia. Group B, significantly different from both of the control groups, shows a partial amnesia.

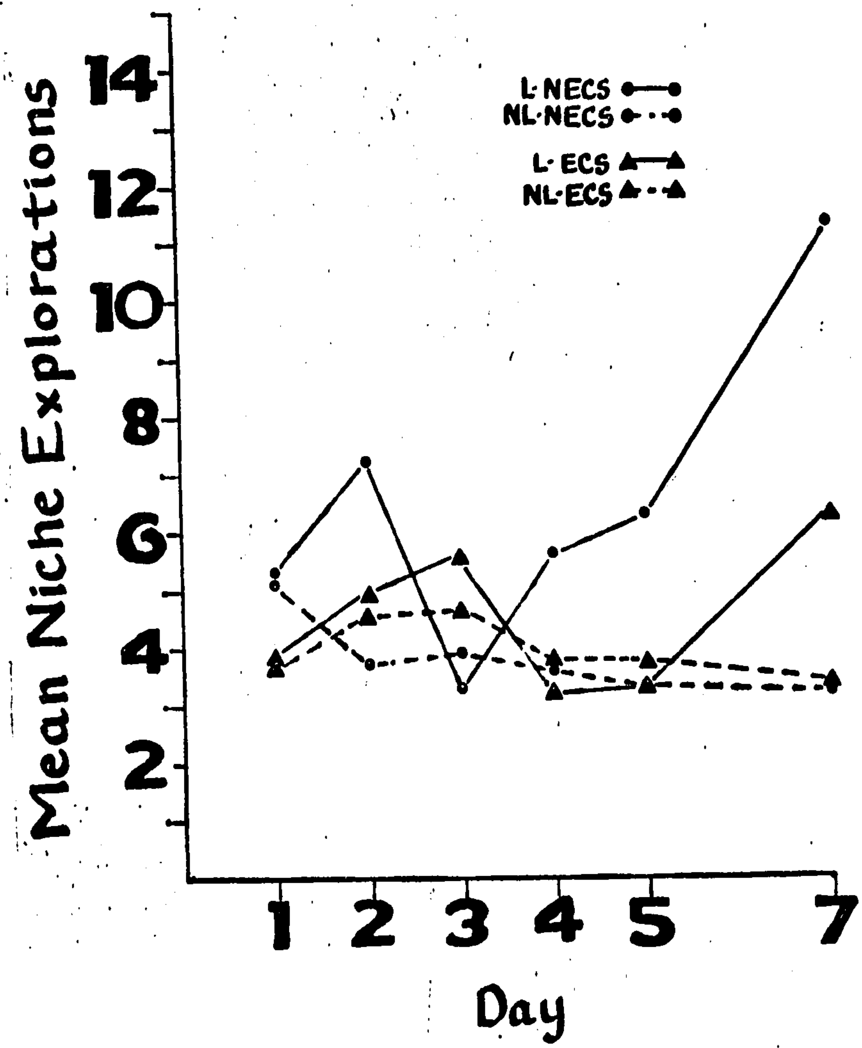

Figure 2. (Experiment 1) Mean niche explorations of each group during each day of the experiment. Days 1-5 were pre-learning; Day 7 was post-learning.

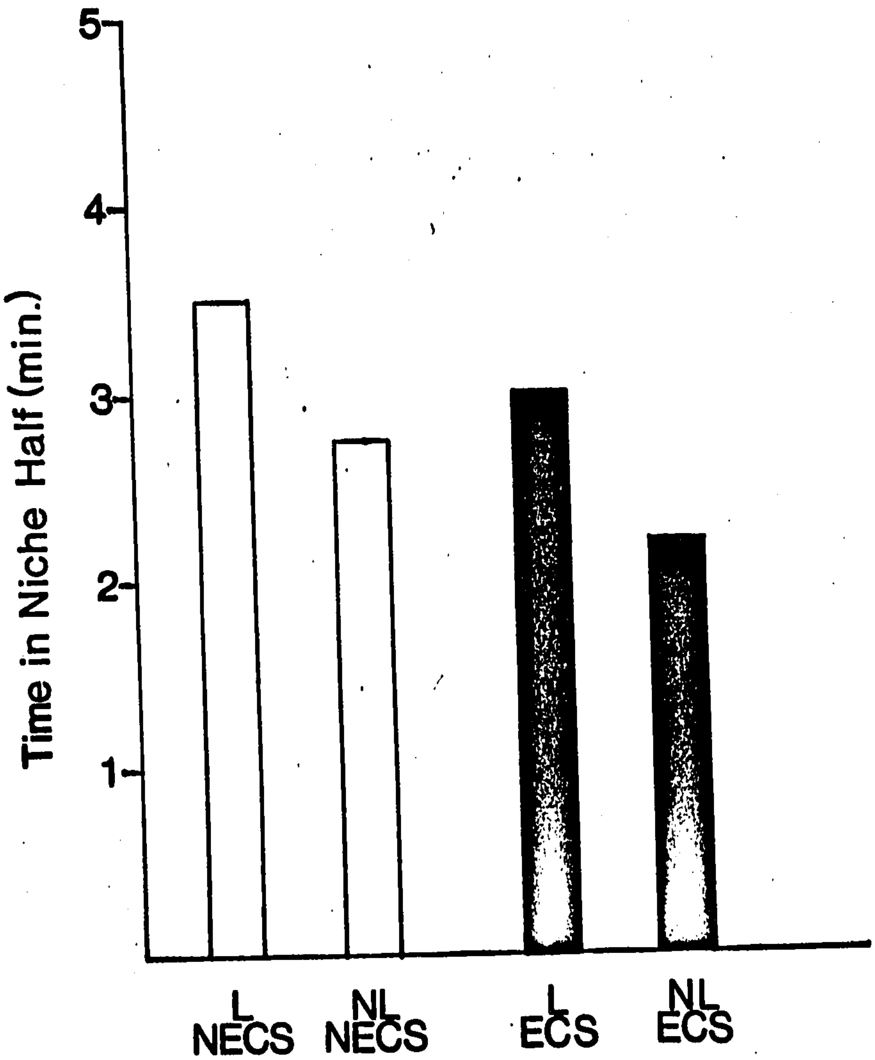

Figure 3. (Experiment 1) Mean time spent in the niche half of the apparatus by each group on Day 7.

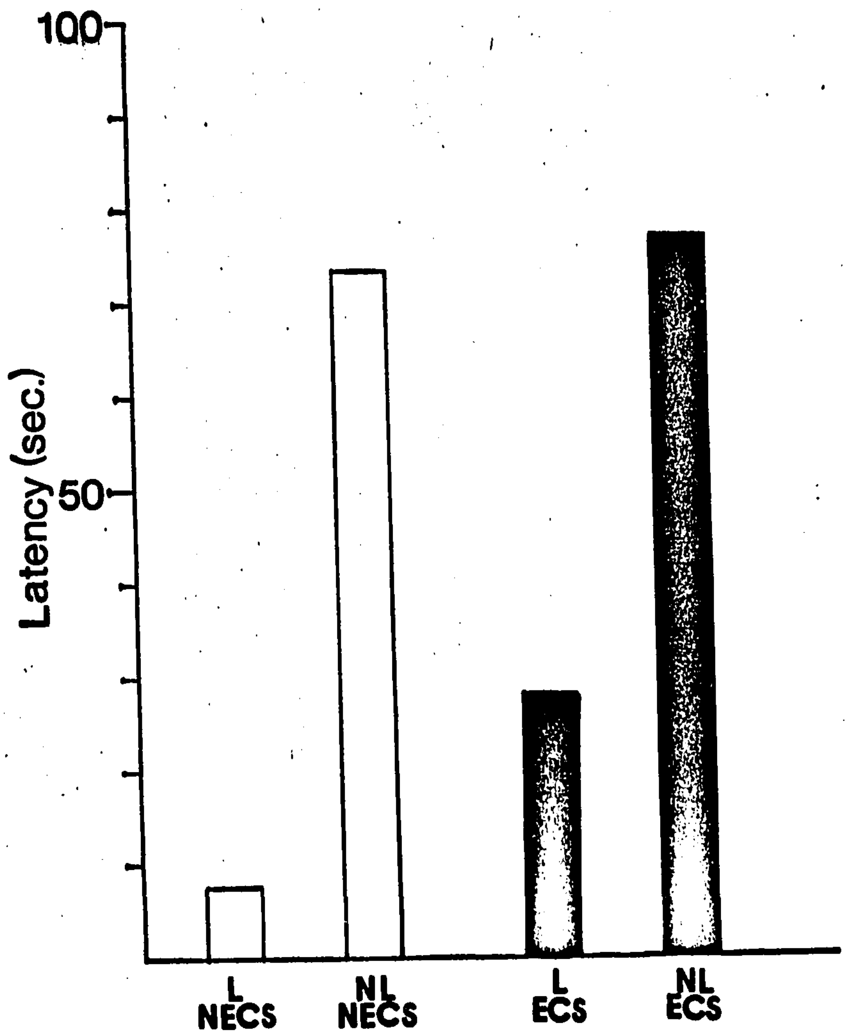

Figure 4. (Experiment 1) Mean latency to the first niche explanation by each group on Day 7.

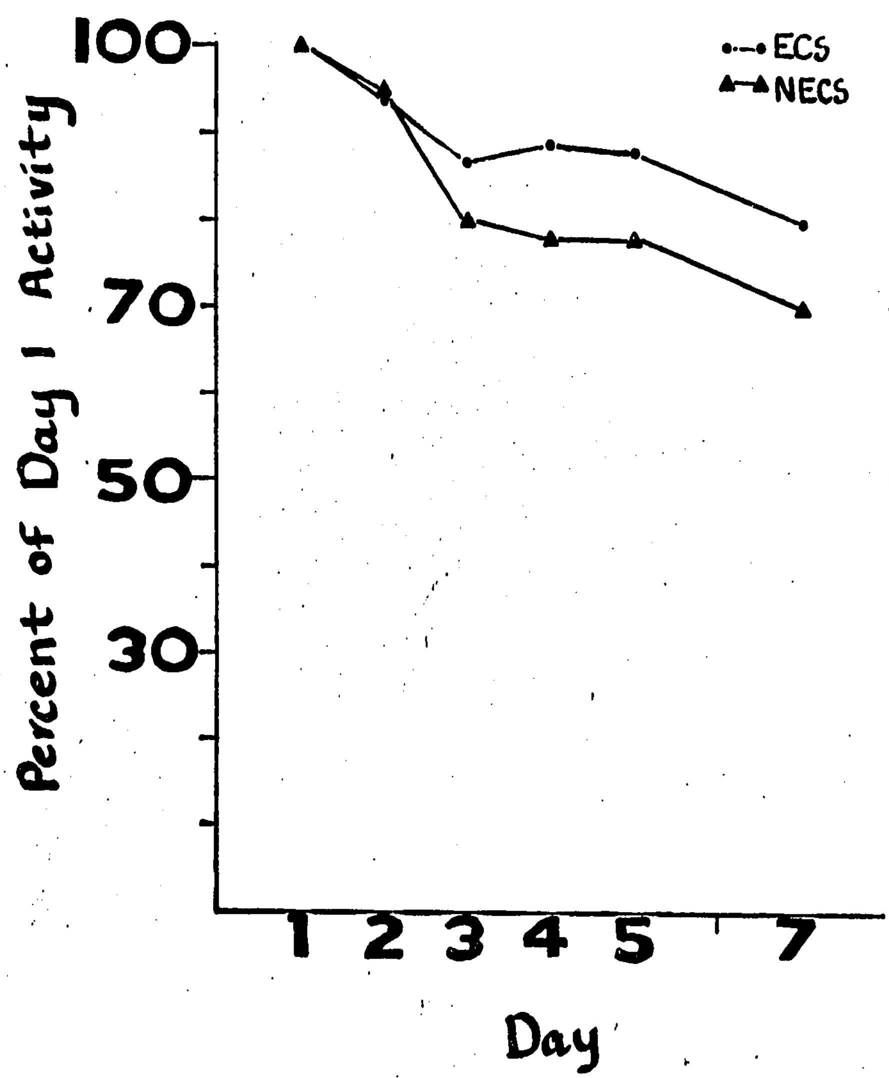

Figure 5. (Experiment 2) Activity in the apparatus before and after an ECS or sham ECS, expressed as a percentage of day 1 activity. Days 1-5 were pre-shock; Day 7 was post-shock.

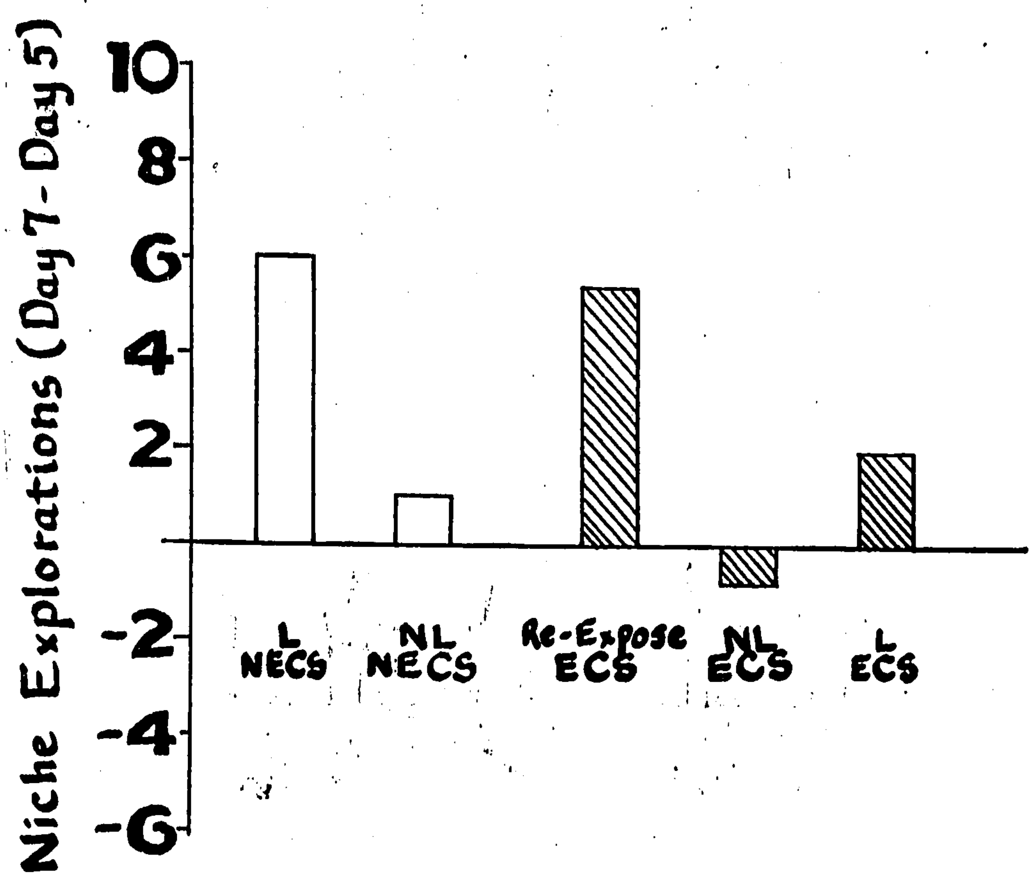

Figure 6. (Experiment 3) Niche exploration before and after various experimental treatments, expressed as a difference between niche explorations on Day 7 (post-learning) minus the niche explorations on Day 5 (pre-learning). A high positive score indicates memory of the reinforcement.

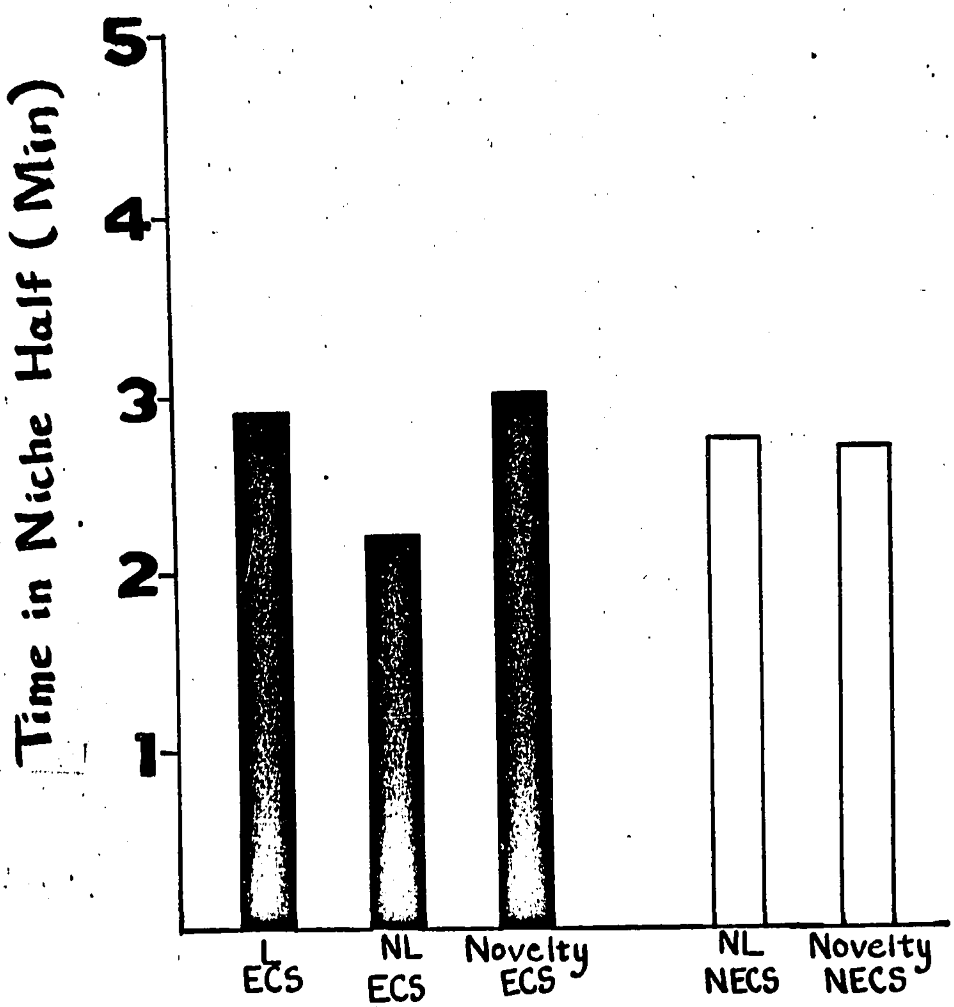

Figure 7. (Experiment 4) Mean time spent in the niche half of the apparatus by each group on Day 7.

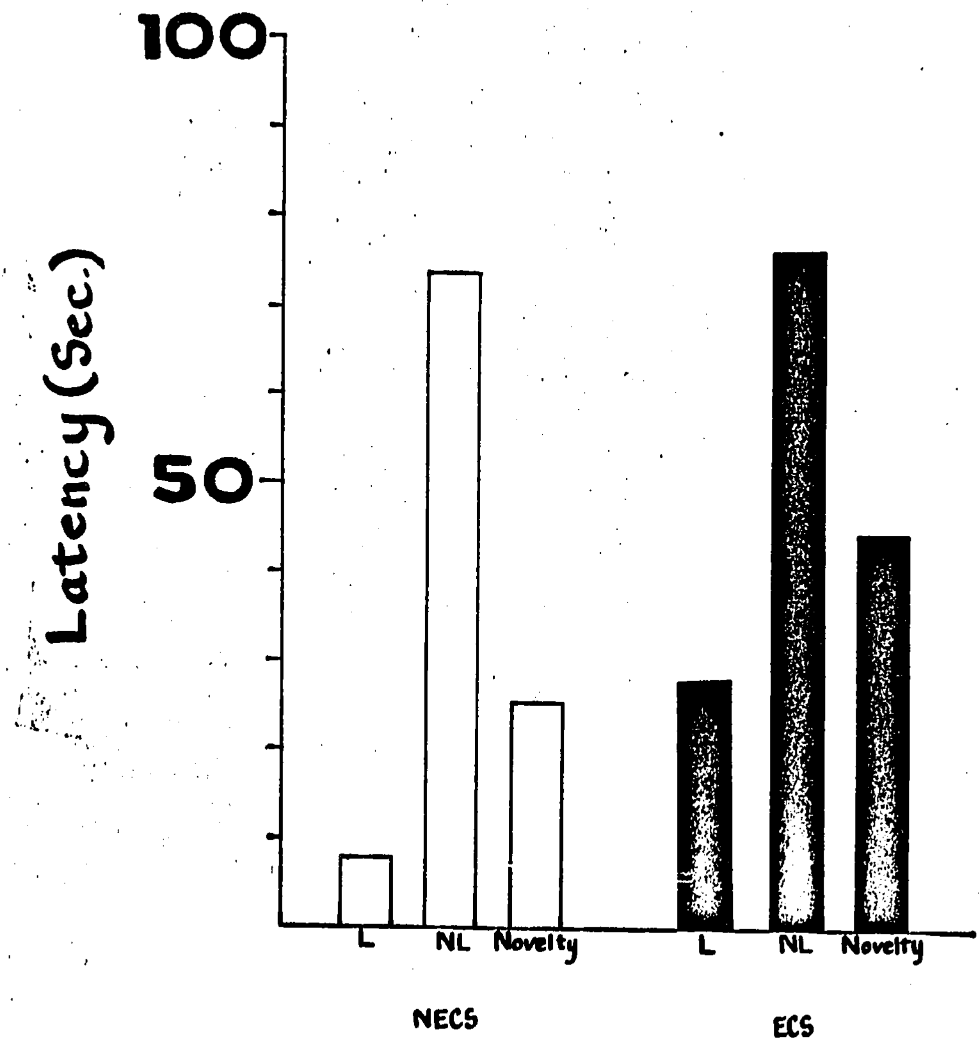

Figure 8. (Experiment 4) Mean latency to first niche exploration by each group on Day 7.

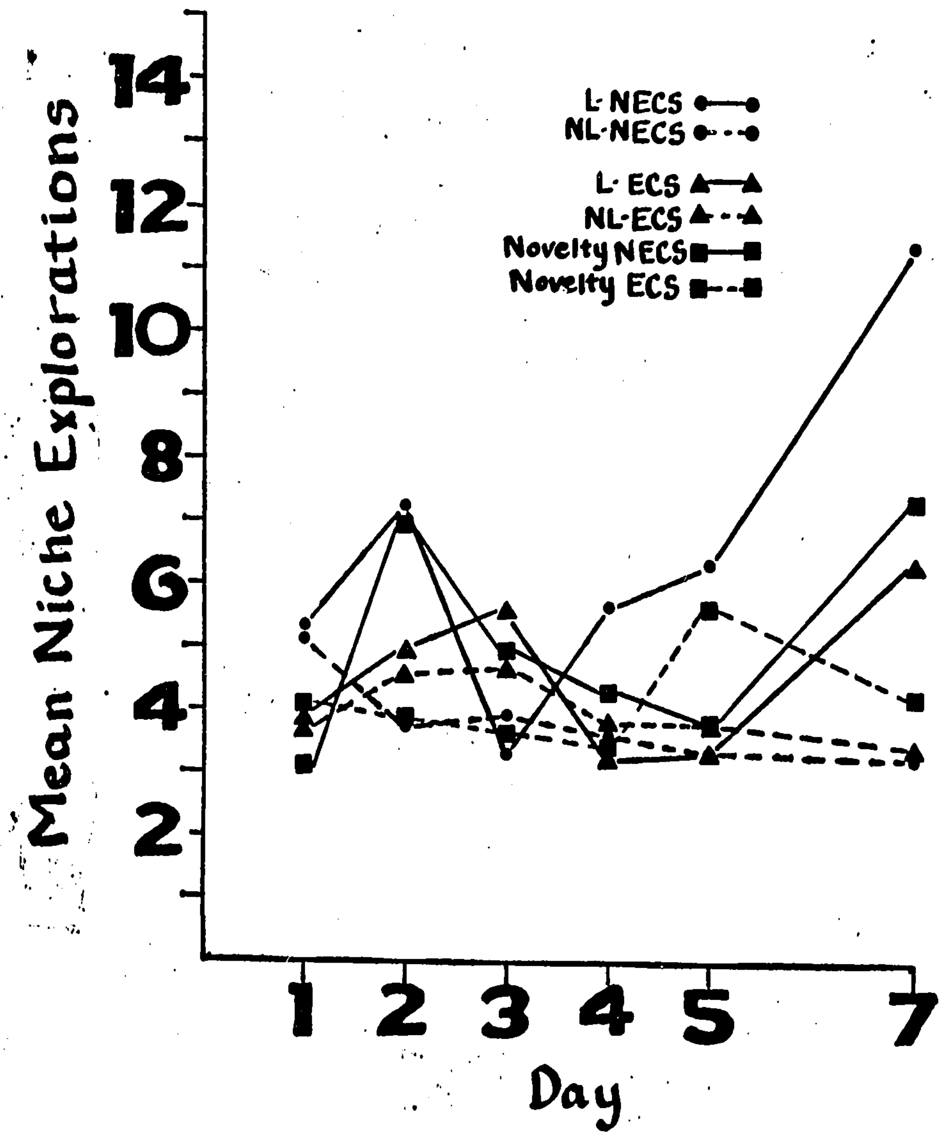

Figure 9. (Experiment 4) Mean niche explorations of each group during each day of the experiment. Days 1-5 were pre-learning; Day 7 was post-learning.

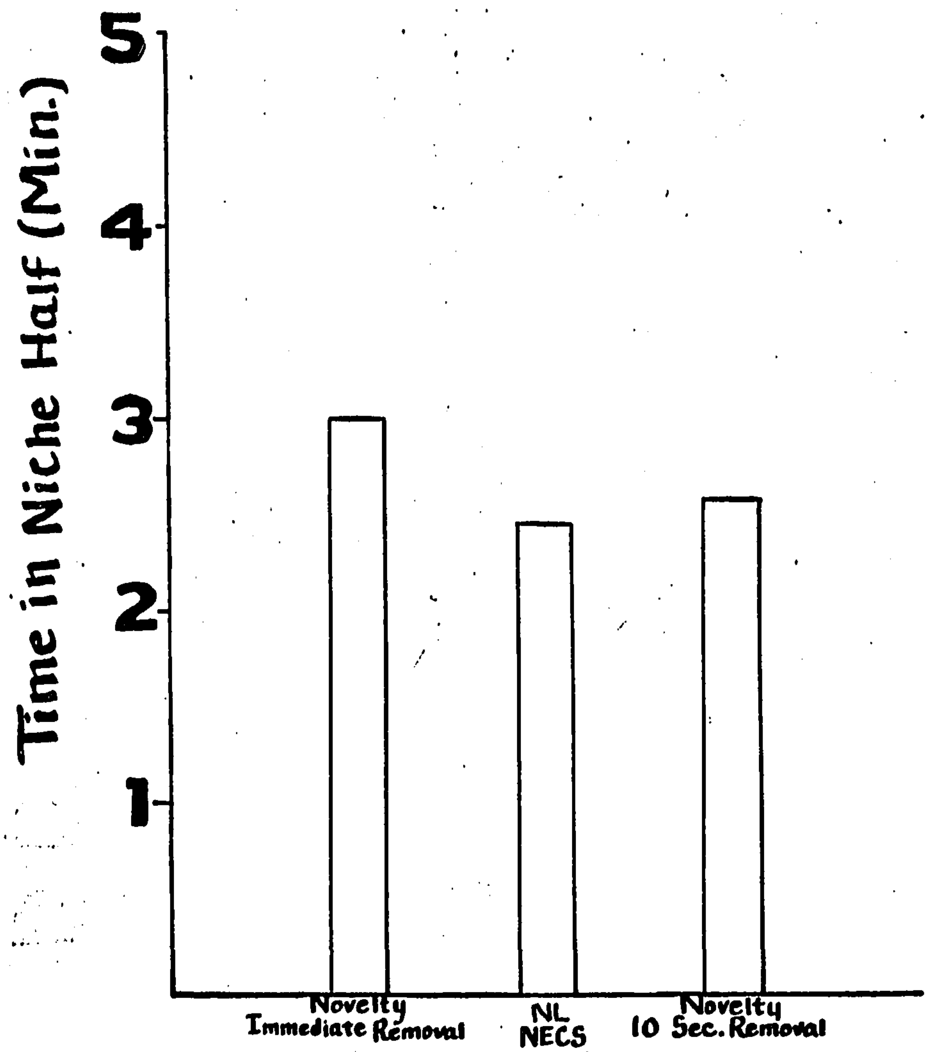

Figure 10. (Experiment 5) Mean time spent in the niche half of the apparatus by each group on Day 7.

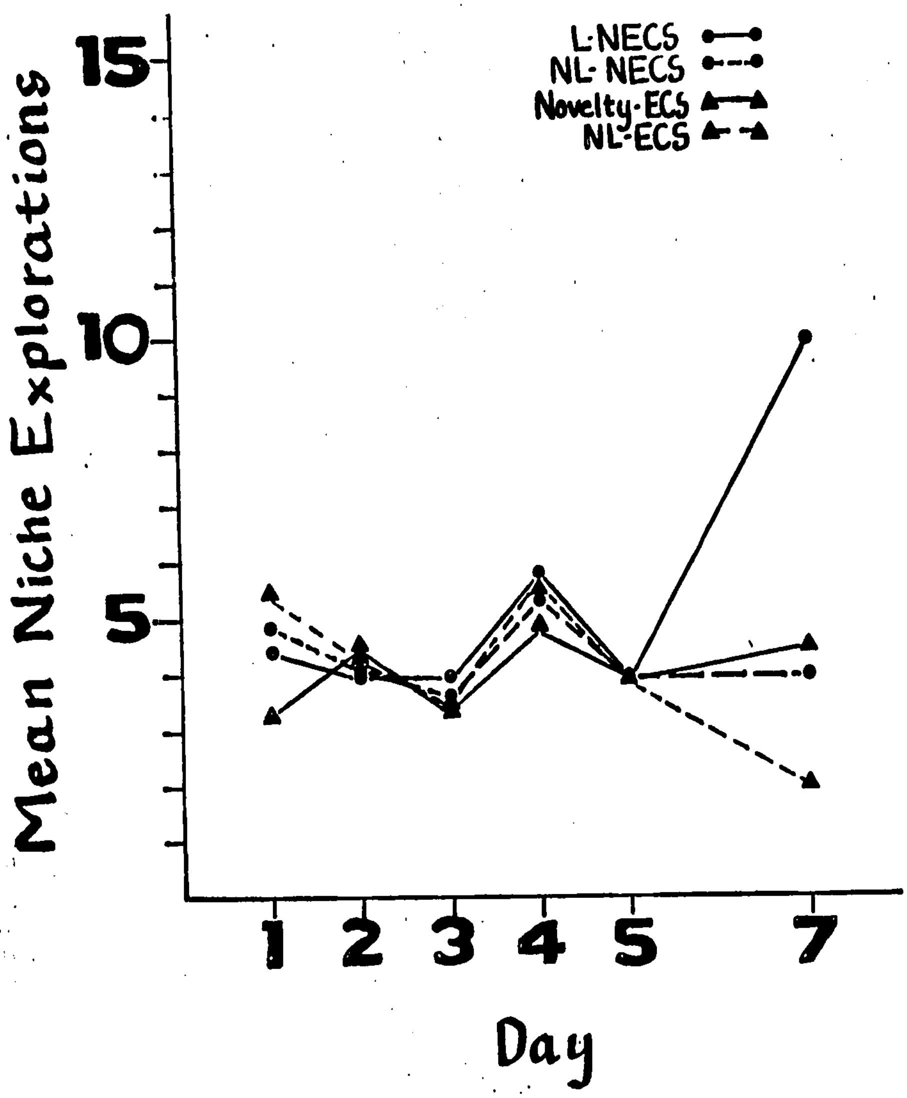

Figure 11. (Experiment 6) Mean niche explorations of each group during each day of the experiment. Days 1-5 were pre-learning; Day 7 was post-learning.

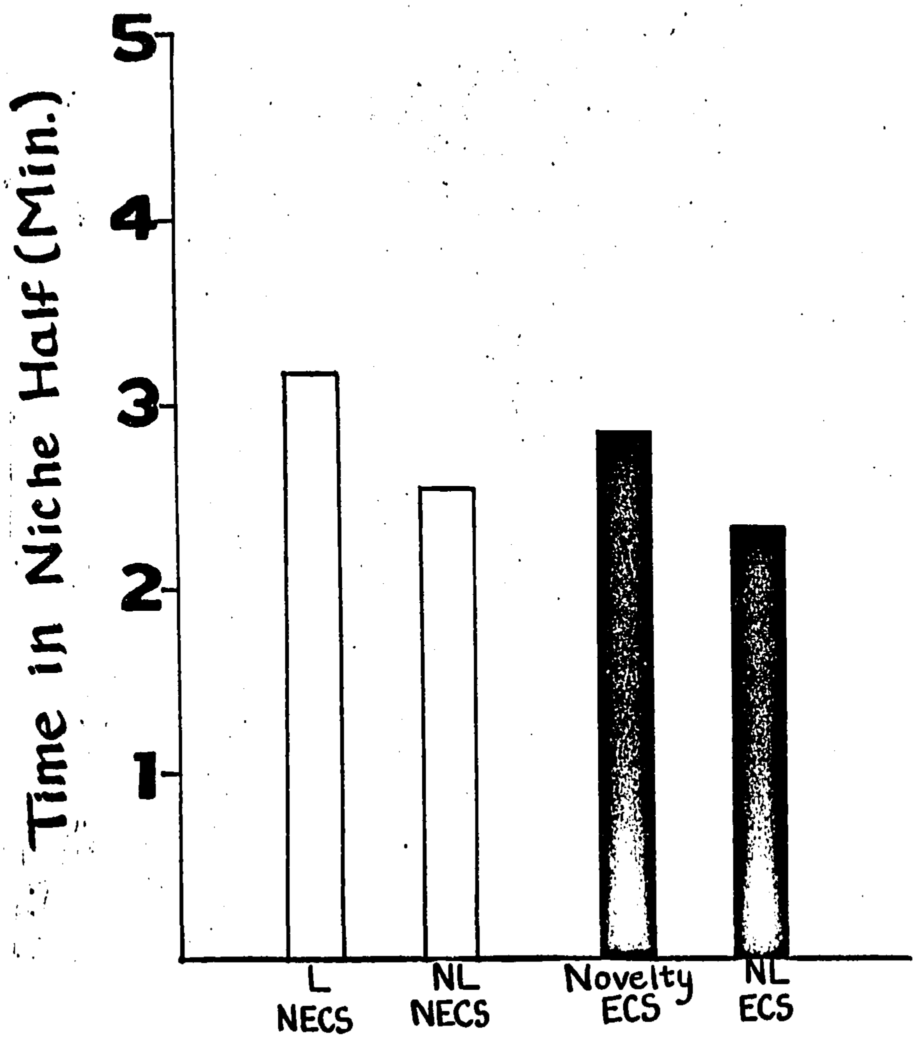

Figure 12. (Experiment 6) Mean time spent in the niche half of the apparatus by each group on Day 7.

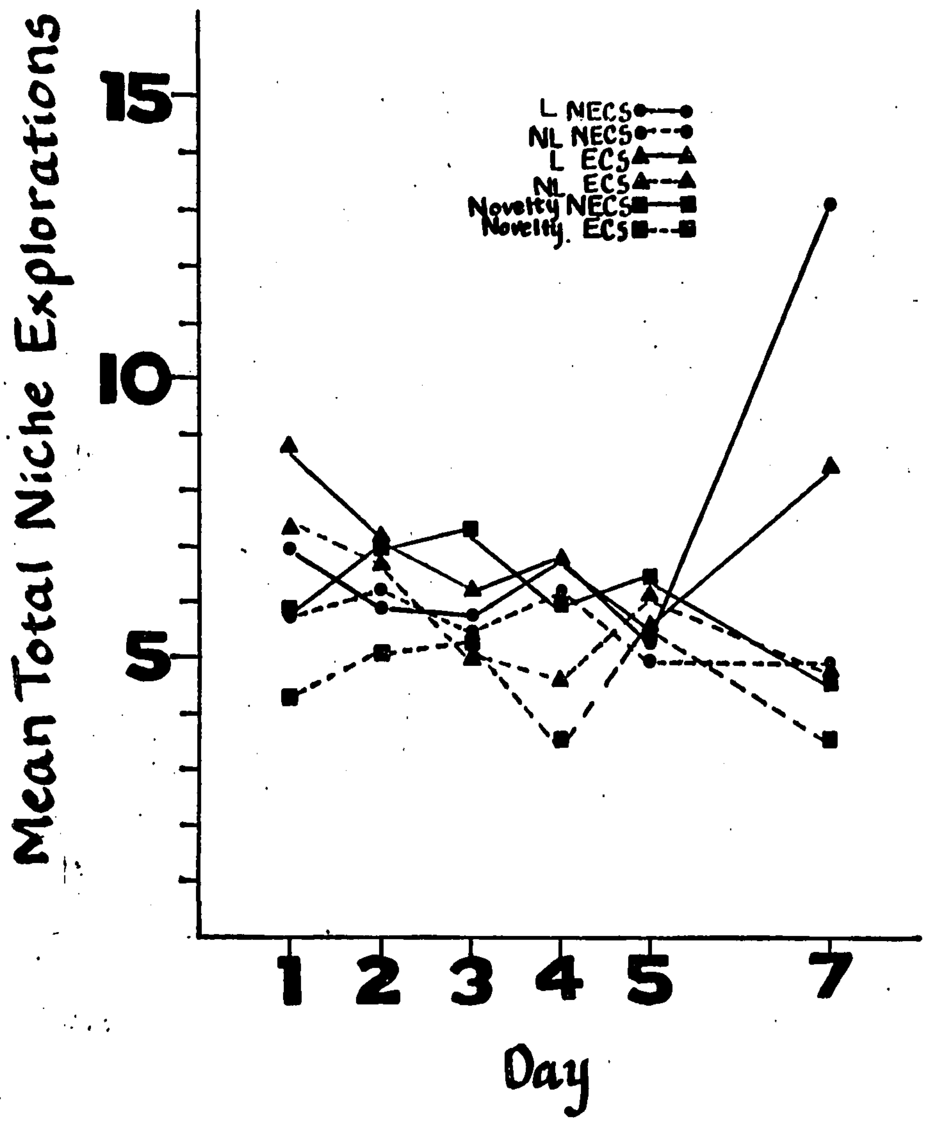

Figure 13. (Experiment 7) Mean niche explorations of each group during each day of the experiment. Days 1-5 were pre-learning; Day 7 was post-learning.

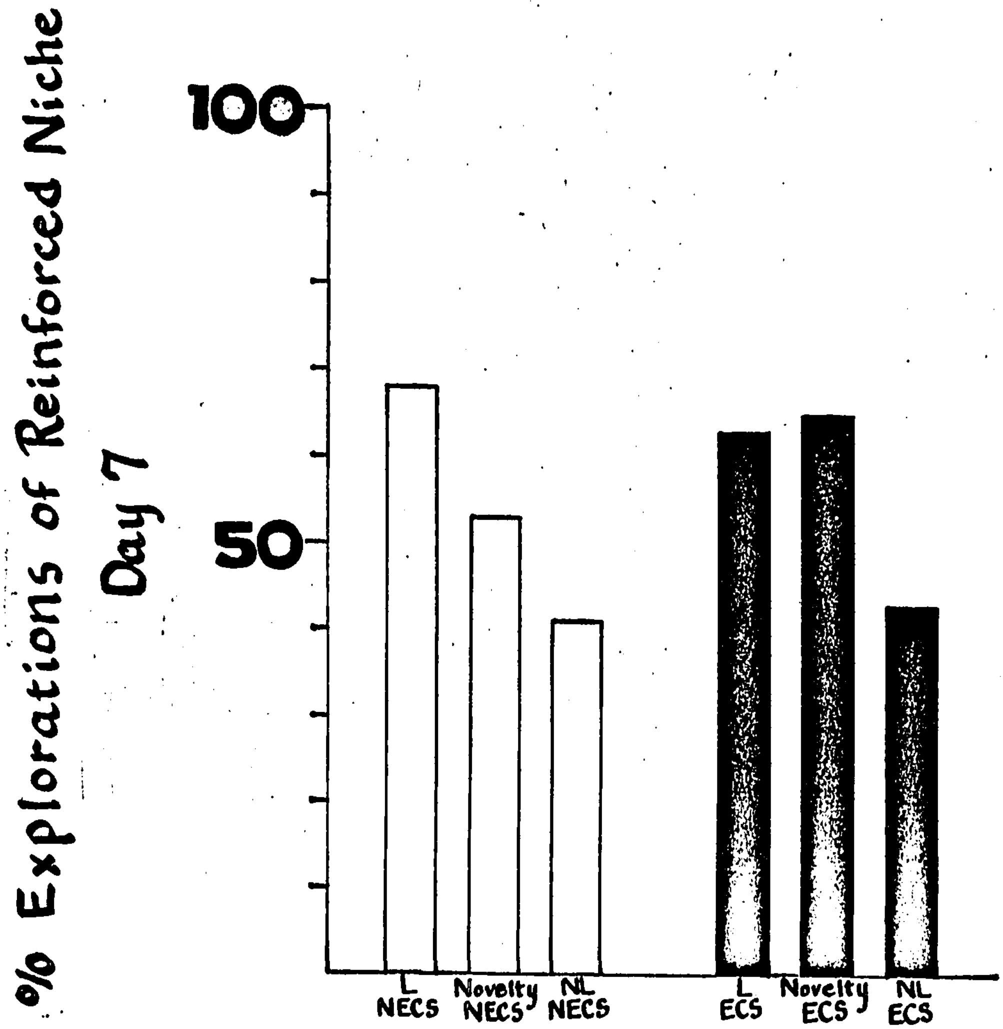

Figure 14. (Experiment 7) Niche preference on Day 7 (post-learning) expressed as the percentage of all explorations that were made to the reinforced niche. See the Method section of Experiment 7 for explanation of this measure regarding the 'no-learning' groups.

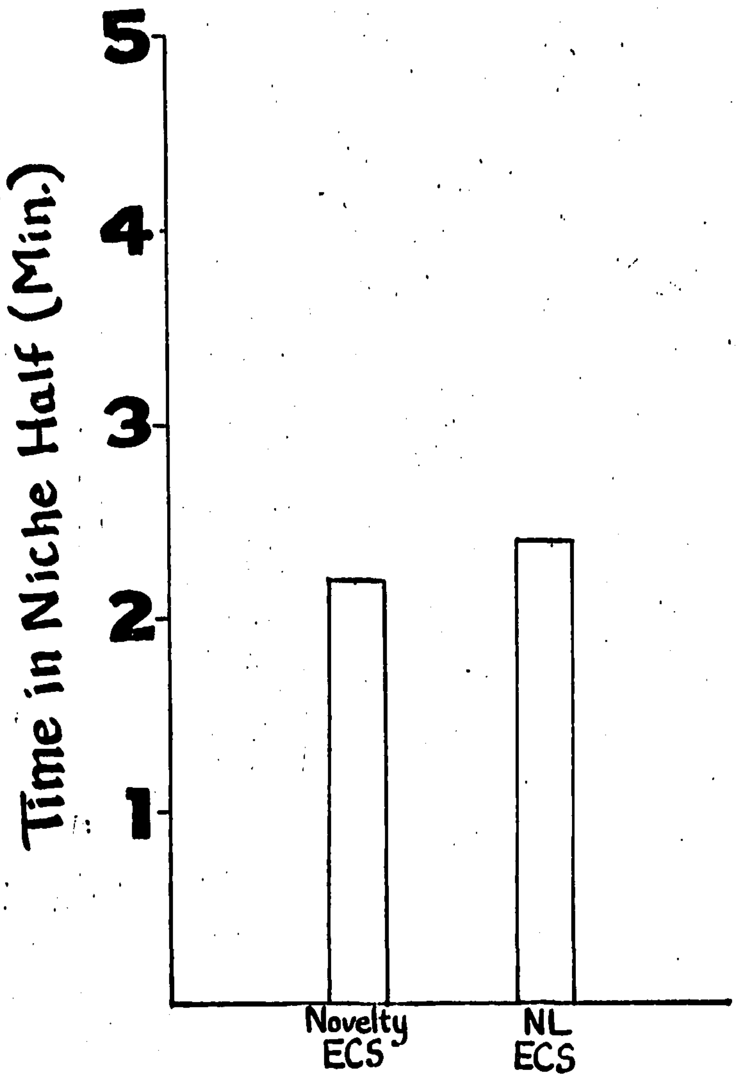

Figure 15. (Experiment 9) Mean time spent in the niche half of the apparatus by each group on Day 7.

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