Inhibitory deficits in rats rendered "mentally retarded" by early brain damage

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Young rats with lesions to the parietal cortex, globus pallidus, or median raphe have previously been reported to be deficient in learning a wide variety of laboratory tasks. The purpose of the current study was to determine whether weanling rats with similarly placed lesions (or with hippocampal or amygdaloid lesions) would subsequently manifest a global deficit in behavioral inhibition (as evidenced by abnormalities on activity, extinction, spontaneous alternation, go/no-go discrimination, passive avoidance, spatial reversal, and visual reversal tests), and whether the degree of this inhibitory deficit would correlate with an independent assessment of learning ability (as gauged by performance on three distinct detour problems). The parietal and median raphe groups showed losses on at least six of the seven tests of inhibition, whereas the remaining groups showed losses on no more than three tests. However, the correlations between overall inhibition scores and learning scores did not exceed .43. Based on a key cluster analysis, two factors were extracted from the data on the inhibition tests. Inhibition related to Factor I (which was strongly associated with learning ability) appeared to underlie the suppression of an initially preferred response in the face of nonreinforcement or punishment. Inhibition related to Factor II appeared to underlie the suppression of an approach response to the negative cue in approach-avoidance and go/no-go discrimination situations. These results are discussed in relation to certain theories of intelligence and mental retardation.

Weanling rats prepared with bilateral lesions to certain parts of the brain (parietal cortex, caudatoputamen, globus pallidus, ventrolateral thalamus, substantia nigra, ventral tegmental area, superior colliculus, median raphe, or pontine reticular formation) have been reported to manifest what appears to be a generalized learning impairment—that is, a learning impairment extending beyond the limits of one sense modality, of one class of laboratory problems, and of one motivational state (Thompson, Huestis, Crinella, & Yu, 1986, 1987). In view of the global nature of this learning impairment, these young brain-damaged rats have been assumed to be "mentally retarded." This assumption should pose no serious conceptual problems, inasmuch as mentally retarded children also manifest a global learning impairment (Clarke & Clarke, 1973; Denny, 1964; Lipman, 1963; Miller, Hale, & Stevenson, 1968; Zeaman & House, 1967).

From a neuropathological point of view, however, such brain-injured rats hardly qualify as animal models of mental retardation, since mental retardation in humans is not usually associated with the kinds of lesions with which our rats were prepared. But from a behavioral perspec-

tive, these brain-damaged animals do have the potential to serve as a useful experimental model of certain classes of mental retardation, on the grounds that both mentally retarded humans and our brain-injured rats evidence a broad behavioral disorder in the domain of problem-solving skills.

One of the more important research areas in mental retardation in which the brain-injured rat could be exploited as a model system deals with the identification of the fundamental cognitive deficit(s) that distinguishes the retarded from the nonretarded. This has been illustrated in a recent series of studies (Thompson, Harmon, & Yu, 1985; Thompson et al., 1986) intended to determine whether rats presumably rendered mentally retarded by early brain damage would exhibit a common defect in behavioral inhibition (as indexed by delayed extinction of a straight-alley task), attention (as indexed by impaired performance on luminous flux discriminations of increasing difficulty), or short-term memory (as indexed by inferior learning under distributed practice as opposed to massed practice). The results disclosed that although some of the brain-damaged groups showed inhibitory, attentional, or short-term memory defects, others did not. Furthermore, it was found that damage to certain brain structures not associated with a generalized learning impairment nevertheless produced disturbances in one or more of these psychological processes. In light of these results, it would seem that neither an inhibitory, nor an attentional, nor a short-term-memory defect is exclusively

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responsible for the production of a global learning impairment.

It should be noted that the foregoing studies contain at least two serious shortcomings. First, they relied on only one test of the presence and extent of each defect, rather than on a battery of tests—which would be preferable, since the processes of inhibition, attention, and short-term memory are probably too broad to be gauged adequately by a single measure. Second, they failed to include an independent assessment of learning ability, and as a consequence, they precluded the possibility of demonstrating the existence of a relationship between the extent of the inhibitory, attentional, and short-term-memory defects and the magnitude of the learning impairment.

Our aim in the present study was to reexamine the hypothesis that an inhibitory defect lies at the basis of the general learning impairment exhibited by young rats with lesions to certain parts of the brain. Unlike what was done in the earlier reports, several measures of the presence of an inhibitory defect were taken, so that the construct of *inhibition* (for our purposes, defined as the withholding of a response that is no longer adaptive), in its broadest sense, could be investigated. In addition, an independent assessment of problem-solving ability was obtained prior to testing for the integrity of inhibitory processes, in order to explore the possibility that the extent of the learning deficit is correlated with the degree of the inhibitory defect. Finally, the diverse behavioral measures obtained in the present experiment permitted the use of methods (e.g., factor analysis) more traditionally employed in psychometric research. One of the more intriguing questions amenable to inquiry with these methods concerns whether or not the various tests of inhibition measure the same thing, and, if not, whether the intertest variability of scores can be accounted for with two or more relatively independent factors or influences.

The selection of an inhibitory defect for study was primarily based on the frequency with which it had been proposed as accounting for deficient learning in the retarded population (Denny, 1964; Heal & Johnson, 1970; Luria, 1963; Porges, 1984; Umetani, Kitao, & Katada, 1985). Although a recent critical review of the psychological literature has questioned the ubiquitous role of an inhibitory defect in the production of learning disturbances (Evans, 1982), there remains a modest though respectable body of physiological (Clausen, 1978; Gandhavadi & Melvin, 1985; Schafer & Peeke, 1982) and behavioral (Levine, 1975; Lobb & Hardwick, 1976; Mosley, 1975; Umetani et al., 1985) evidence that a disorder in central inhibitory mechanisms is a major feature of mental retardation. Besides, the comparative psychological literature contains compelling arguments for the importance of inhibitory processes in learning (Diamond, Balvin, & Diamond, 1963; Harlow & Mears, 1979; Stenhouse, 1973).

Specifically, weanling rats were subjected to bilateral lesions to certain parts of the brain (parietal cortex, glo-

bus pallidus, or median raphe) known to induce a generalized learning impairment. (Other brain sites that could also have been selected for study, such as the substantia nigra or pontine reticular formation, were excluded from consideration, because a high proportion of young rats bearing these lesions would not likely survive the extended periods of water or food deprivation demanded by some of the tasks employed in the current experiment.) After a 3-week recovery period, these brain-damaged animals along with sham-operated controls were observed on three distinct detour problems that provided an estimate of their problem-solving skills (see Thompson, Harmon, & Yu, 1984a, 1984b). This set of problems was investigated, because a recent analysis (Crinella, Thompson, Fisher, & Yu, 1989) of over 300 brain-damaged and sham-operated rats tested on six different learning tasks revealed that performance on the detour problems was the most sensitive measure of global learning ability or *g* (general intelligence). Subsequently, the animals were given seven separate behavioral tests, each of which ostensibly measured some aspect of inhibitory processes. These tests included measures of activity, extinction, spontaneous alternation, go/no-go discrimination, passive avoidance, spatial reversal learning, and visual reversal learning. For comparative purposes, rats with lesions to either the hippocampus or amygdala were also investigated. Although the foregoing limbic forebrain lesions do not lead to a generalized learning impairment (Thompson et al., 1986), they have been reported to induce deficits on certain laboratory tasks whose successful performance requires some degree of behavioral inhibition (Douglas, 1967; Goddard, 1964; Kimble, 1969; Pellegrino, 1968). Thus, the inclusion of these two groups was expected to provide data on the extent to which inhibitory deficits are specific to rats with brain lesions that cause a generalized learning impairment.

METHOD

Subjects and Surgery

Weanling (22–25-day-old) male Sprague-Dawley albino rats, 55–65 g, underwent surgery under deep chloral hydrate anesthesia (400 mg/kg). The lesions in four experimental groups were accomplished electrolytically, by passing a constant anodal current of 1.2–2.0 mA for a duration of 10 sec through an implanted stainless steel electrode (.5 mm in diameter) with 1.0 mm of the tip exposed. One of these groups (Group GP) sustained bilateral lesions to the globus pallidus (with the head of the rat oriented horizontally in the stereotaxic headholder, the coordinates were 7.0 mm anterior to lambda, 2.7 mm lateral to the longitudinal sinus, and 6.0 mm ventral from the surface of the brain); the second (Group MR) received a single midline lesion to the region of the median raphe (1.0 mm anterior and 7.5 mm ventral); the third (Group H) was subjected to multiple bilateral lesions to the dorsal hippocampus (5.0 mm anterior, 1, 2, and 3 mm lateral, and 3.5 mm ventral); and the fourth (Group A) suffered bilateral lesions to the amygdaloid complex (6.0 mm anterior, 4.0 mm lateral, and 7.0 mm ventral). The fifth group (Group PC) sustained bilateral lesions to the parietal cortex (middle third of the cerebral cortex) by means of the suction method, and the last group (Group C) served as oper-

ated controls, undergoing the same surgical procedure as the experimental groups, save for drilling of the skull and lesioning of the brain.

Following surgery, the animals were usually housed, 2 or 3 per cage, in medium-sized hanging wire cages that contained a constant supply of food pellets and water. A dish of sweetened wet mash was placed daily in each cage during the 1st postoperative week, to encourage early resumption of food intake. During the 3rd postoperative week, the animals were handled daily for approximately 5 min. During this handling period and the subsequent period devoted to behavioral testing, the experimenters were unaware of the group to which each subject belonged. All the animals were maintained on a 12:12-h light:dark cycle with lights on at 0600; they were trained only during the light phase.

Apparatus

Detour Box

The detour apparatus, whose dimensions have been reported elsewhere (Thompson et al., 1984a), was divided into a startbox painted flat white, a choice chamber painted flat white, and a goalbox painted flat black. An opaque guillotine door separated the startbox from the choice chamber. Interchangeable partitions inserted between the choice chamber and goalbox permitted this apparatus to be used for the presentation of the three detour problems, the extinction problem, and the go/no-go visual-tactile discrimination problem.

Detour problems. During preliminary training, a partition containing a centrally located window at floor level was employed. For Problem A, the partition used in preliminary training was placed in the apparatus along with a platform that sloped upwards into the choice chamber to a maximum height of 10.1 cm above the floor (see Figure 1, top panel). Problem B consisted of a partition containing a centrally located plastic cylinder that extended into the choice chamber and was elevated 5.7 cm above the floor (Figure 1, middle panel). Problem C consisted of a partition containing a window located above the floor level that could be reached only by climbing a vertically positioned ladder that extended into the choice chamber (Figure 1, bottom panel). (For Problems B and C, a ramp located behind the partition allowed the rat to descend to the floor of the goalbox.)

The entire apparatus was covered by a transparent Plexiglas lid and illuminated by conventional fluorescent ceiling lights.

Extinction problem. The partition used for this problem contained a centrally located window at floor level, with a hinged door that had to be pushed open to gain access to the goalbox.

Go/no-go discrimination problem. The same partition as that used for the extinction problem was employed. For the *go trials*, the choice chamber was fitted with a black sandpaper (80 grit aluminum oxide) floor. For the *no-go trials*, the regular wooden floor (white, smooth surface) of the apparatus was exposed. The hinged door was unlocked during the *go trials* and locked during the *no-go trials*.

Activity Box

Activity was measured in an enclosed rectangular box (90 × 64 × 30 cm) painted flat black and covered by a smoked Plexiglas lid. By means of luminous paint, an iridescent grid pattern consisting of 12 21.5-cm squares was inscribed on the floor of the box. Observations were made in a semidarkened room.

Passive Avoidance Box

This apparatus consisted of a two-compartment box. The large illuminated compartment (38 × 32 × 25 cm) was painted flat white and contained a wooden floor and a transparent Plexiglas lid. The small dark compartment (32 × 18 × 25 cm) was painted flat black and contained a grid floor and a Plexiglas lid painted flat black on the outside. An opening (15.5 × 7.5 cm) at one end of the illuminated compartment gave access to the dark compartment. A guil-

Figure 1. Schematic drawing of the detour apparatus, showing the startbox (SB), choice chamber (CC), and goalbox (GB). The interrupted lines mark the boundaries of the blind alleys. On Problem A (top panel), the rat must mount the raised platform in order to gain access to the goal box. On Problem B (middle panel), the rat must enter the elevated cylinder to reach the goalbox. On Problem C (lower panel), the rat must climb the ladder to reach the goalbox.

lotine door could be lowered to block entrance into the dark compartment. The grid floor was connected to a Variac, which delivered footshocks with an average intensity of 3.5 mA.

The entire apparatus was located in a sound-attenuated room illuminated by conventional fluorescent ceiling lights.

T-Maze

The enclosed single-unit T-maze contained alleys measuring 15.2 cm wide and 25.4 cm high, which were covered by a transparent Plexiglas sheet. The startbox (stem) was 33.5 cm long, and the arms were 33.0 cm. At the end of each arm was a window through which the rat could enter an endbox (15.2 × 30.4 × 25.4 cm) on that side. The startbox and arms of the T had a grid floor; each endbox had a wooden floor.

This apparatus was used to test for spontaneous alternation and was subsequently used to train the animals on a series of spatial reversal problems with escape-avoidance of footshock (1.0–1.2 mA) as a motive.

Visual Discrimination Box

A modified Thompson-Bryant discrimination box utilizing the motive of escape-avoidance of footshock was employed to train the animals on a series of visual discrimination reversal problems (see Thompson et al., 1985, for a complete description of this apparatus). The startbox and choice chamber contained a grid floor and a clear Plexiglas lid, and the goalbox contained a wooden floor and an opaque lid. Two windows (14.0 cm²) spaced 5.0 cm apart and appearing at the end of the choice chamber provided the only means by which the animal could enter the goalbox. Each window

contained a hinged milk glass door that could be transilluminated by a light source located behind the goalbox. When measured in the choice chamber at a distance of 10.0 cm from the illuminated door, a Gossen Luna-Pro exposure light meter gave an average reading of 460 lx. An average reading of less than 2 lx was obtained from the unilluminated door.

The discrimination box was housed in a sound-attenuated windowless room illuminated by a shielded 25W fluorescent light.

Procedure

Following a 3-week recovery period, the animals were weighed and subsequently trained (or observed), in succession, on eight different tasks. Three of these tasks (detour, extinction, and go/no-go discrimination problems) were appetitively motivated, each requiring the initiation of a water deprivation schedule lasting 7 days. Three additional tasks (passive avoidance, spatial reversal, and visual reversal problems) were aversively motivated by footshock. The remaining two tasks (locomotor activity and spontaneous alternation) were entirely governed by intrinsic activity-exploratory tendencies. Each task required a total of 5 days (Monday through Friday) to complete. The purpose of the first task (detour problems) was to provide an index of general learning ability; the remaining seven tasks were intended to measure some aspect of inhibitory processes related to behavior. All the animals were given these tasks in the order in which they are described below. Apart from the tests of activity, spontaneous alternation, and passive avoidance, the animals were usually run in squads of two or three.

Detour Problems

On the 1st day (following 2 days of water deprivation), each animal (now 43–46 days of age) was allowed to explore the apparatus for 10 min. The guillotine door between the startbox and choice chamber remained in the raised position and a dish of water as well as a dish of sweetened wet mash were available in the goalbox for the animals to consume. On the 2nd day, the animals were given 10 preliminary training trials with intertrial intervals of 90–180 sec. Each trial began with the placing of the animal in the startbox and the raising of the startbox door. In most cases, the animal would readily leave the startbox, traverse the choice chamber, enter the goalbox through the centrally located window, and ingest the water or mash. After 10 sec, the animal was carried to a holding cage to await the next trial. On the 10th trial, the animal was allowed to ingest the water and mash for approximately 200 sec.

Problem A was presented on the 3rd day, Problem B on the 4th day, and Problem C on the 5th day. Five trials were given on each problem, with intertrial intervals of approximately 90–300 sec. The training procedure was the same as that described for preliminary training.

With respect to Problem A, the route to the goalbox involved mounting the raised platform. An error consisted of passing under the raised platform by at least the length of the animal's body (excluding the tail). For Problem B, the route to the goalbox involved entering the elevated cylinder. An error in this case consisted of traversing beyond the opening of the cylinder by at least the length of the animal's body. Finally, the route to the goalbox on Problem C involved climbing the ladder, and an error consisted of traversing beyond the ladder by at least the length of the animal's body (see Figure 1). Total (initial combined with intratrial repetitive) errors were recorded on each trial. Further details of the training procedure have been reported elsewhere (Thompson et al., 1984a).

Activity

On the 1st day, each animal was placed in the center of the floor of the activity box and allowed to explore during a 5-min period. The number of squares entered by all four paws was recorded. (The number of rears made was also counted.) This procedure was repeated over the next 4 days.

Extinction Task

Acquisition training. On the 1st day (after 2 days of water deprivation), the animal was inserted into the startbox of the detour apparatus and the startbox door raised. Typically, the animal exited from the startbox, traversed the choice chamber, pushed open the door of the partition, and entered the goalbox. (In this experiment, the two dishes that contained water and mash were positioned to one side so that the animal could not see them until fully entering the goalbox.) The animal was allowed to ingest the food and water for 10 sec, after which it was transferred to a holding cage to await the next trial. Six trials were given with intertrial intervals of approximately 30–60 sec. On the last trial, the animal was permitted to ingest the water and mash for a maximum of 200 sec. For each trial, time (measured to the nearest .2 sec) was recorded from the moment the startbox door was raised to the moment the animal placed all four paws within the threshold of the goalbox. These time scores were transformed to speed scores (in centimeters/second) for statistical purposes.

This procedure was repeated over the next 3 days.

Extinction training. This phase of the experiment, which was instituted on the 5th day, required that neither the dish of water nor the dish of mash be present in the goalbox. The procedure followed during extinction was the same as that described for acquisition, except that 11 trials were given and the intertrial intervals ranged from 30 to 120 sec. If the animal failed to enter the goalbox within 60 sec, it was removed from the choice chamber (or startbox) and returned to the holding cage to await the next trial.

It should be noted that running speed on the first extinction trial, designated Trial 0, can be treated as the last measure of acquisition, whereas running speeds on the remaining trials, designated Trials 1–10, are treated as measures of extinction.

Spontaneous Alternation

The rats were tested individually for spontaneous alternation twice daily (once in the morning and once in the afternoon with a separation of at least 4 h) for 5 consecutive days. Each test began with the initial placing of the rat into the starting alley of the T. The animal was allowed to explore the maze and make a free choice of either the left or right arm. After complete entry into one of the arms, the animal was confined therein for 5 sec, then removed and placed in a holding cage. A second trial was administered after a 15-sec intertrial interval. On the basis of the directional choice (i.e., right or left) of the second trial, each rat's behavior was classified as either alternating (choosing the opposite arm from that in Trial 1) or not alternating (choosing the same arm as that in Trial 1).

Go/No-Go Discrimination

The cues for this visual-tactile discrimination involved a black rough floor (positive) versus a white smooth floor (negative). In the presence of the positive cue, an approach response to the unlocked door of the partition admitted the animal to the goalbox, which contained the usual dishes of water and wet mash. In the presence of the negative cue, the door of the partition was locked (although it could be moved slightly before contacting the lock), which prevented the animal from entering the goalbox. The rotation of the positive and negative cues followed a sequence mixed with single- and double-alternation runs. Six trials were given daily for 5 consecutive days with an intertrial interval of 30–120 sec.

The specific training procedure was as follows: The animal was placed in the startbox of the detour apparatus and the startbox door raised. Time was measured (to the nearest second) between the moment the startbox door was raised and the moment the animal touched the door of the partition. If the positive cue was present, the animal could push open the unlocked door and proceed to the water and mash, which it could ingest for 10 sec. If the negative cue was present, the animal was confined to the choice chamber for 10 sec after it initially touched (moved) the door. The animal

was then removed from the goalbox (or choice chamber) and transferred to the holding cage to await the next trial. In the case that the animal failed to touch the door within 60 sec on a negative trial, it was removed from the choice chamber (or startbox) and returned to the holding cage. (If this occurred on a positive trial, the animal was assisted in pushing open the unlocked door and entering the goalbox.) On the last trial of each day, the animal was allowed to ingest the water and food for approximately 200 sec.

Passive Avoidance

In this experiment, one trial a day was given for 5 consecutive days. Preparatory to a trial, the rat was placed in the illuminated compartment. A trial was initiated with the raising of the guillotine door separating the dark compartment from the illuminated compartment. If the rat entered the dark compartment—all four paws being within the threshold—individual footshocks were administered at a rate of about one every 2 sec until the rat returned to the illuminated compartment (all four paws being outside of the threshold). No further footshocks were given unless the animal reentered the dark compartment. The trial was terminated when the animal refrained from entering the dark compartment for 5 min.

Spatial Reversal Learning

On the 1st day, all the animals were originally trained in the T-maze to run from the startbox, choose the right arm, displace the unlocked gray card blocking the window, and enter the endbox in order to escape from (or avoid) footshock. If the left (incorrect) arm was chosen, the animal automatically received footshock in front of the locked card (preventing the animal from entering the endbox on that side) and was forced to choose the right arm of the T. The animal was confined to the endbox for 10 sec, after which it was transferred to the holding cage to await the next trial. With an intertrial interval of 50–70 sec, training to the correct (right) arm was continued in one session until the animal reached the criterion of learning—the first appearance of a “perfect” or “near-perfect” (Runnells, Thompson, & Runnells, 1968) run of correct responses having a probability of occurrence of less than .05.

The specific training procedure was as follows: The animal was placed in the startbox and the startbox door raised. Failure to leave the startbox within 5 sec was followed by footshocks until the animal entered one of the arms. No further footshocks were administered unless the animal made an error (an approach to within 10.8 cm of the locked card) or failed to traverse the entire length of the chosen arm within 5 sec. Total errors (the number of approach responses to the locked card that resulted in footshock) were recorded on each trial.

On the following day, all the animals were started on a series of four reversal problems, one reversal problem every 24 h. The first reversal required the choice of the left arm, the second reversal required the choice of the right arm, etc. The training procedure was the same as that described in original learning.

Visual Reversal Learning

On the 1st day, all the animals were originally trained under the motive of escape-avoidance of mild footshock to approach the unlocked illuminated door (positive) and to avoid the adjacent locked unilluminated door (negative) in order to gain access to the goalbox. An approach response to within 7.5 cm of the unilluminated door (an error) was automatically punished by footshock, the animal subsequently being forced to respond to the illuminated door in order to gain entrance to the goalbox. The animal was confined to the goalbox for 10 sec, after which it was carried to the holding cage to await the next trial. The position of the illuminated (and unilluminated) door was varied from the right to the left window in a sequence mixed with single- and double-alternation runs. With an intertrial interval of 50–70 sec, training to the illuminated door continued in one session until the animal reached the criterion of learning (the same as that used in spatial reversal learning).

The specific training procedure was as follows: The animal was placed in the startbox and the startbox door raised. Failure to leave the startbox within 5 sec was followed by footshocks until the animal entered the choice chamber. No further footshocks were given unless the animal made an error or failed to make a choice of one of the doors within 5 sec. Total errors (the number of approach responses to the negative door that resulted in footshock) were recorded on each trial.

On the following day, all the animals were started on a series of four reversal problems, one reversal problem every 24 h. The first reversal required choosing the unilluminated door, the second reversal required choosing the illuminated door, etc. The training procedure was the same as that described for original learning.

Statistical Analyses and Measurements of Performance

The principal analyses of the behavioral data were accomplished with the use of a groups $\times$ days (trials, problems) analysis of variance, using the BMDP (University of California Press) statistical software. In most cases, these analyses were supplemented by non-parametric tests applied to particular scores that reflected overall (or final) performance on each of the eight tasks. These particular scores were used not only in calculating the intercorrelations among the tasks, but in performing a key cluster analysis (Tryon & Bailey, 1970). In every case, the scores chosen for analysis were comparable to each other to the extent that higher values (relative to those of the controls) reflected deficits of increasing severity. These scores were as follows:

1. Detour performance: pooled errors committed on Trials 1–5 for all three problems.
2. Activity: the total number of squares entered during the 5-day test (the total number of rears was also investigated).
3. Extinction: the mean time score for Extinction Trials 3–10 was calculated, converted into a reciprocal, and multiplied by 100.
4. Spontaneous alternation: the number of tests in which the animal failed to alternate.
5. Go/no-go discrimination: the ratio of the mean time score for the three positive trials to the mean time score for the three negative trials on the last day of training (this score reflects final performance on the discrimination).
6. Passive avoidance: the total number of entrances into the dark compartment during the 5-day test.
7. Spatial reversals: the total errors committed on the four reversal problems.
8. Visual reversals: the total errors committed on the four reversal problems.

Histology

At the conclusion of postoperative testing, each brain-damaged rat (by now 99–102 days old) was killed with an overdose of chloral hydrate, its vascular system perfused with 10% formalin, and the brain removed and stored in 10% formalin for 2–4 days. The cortical lesions were reconstructed on Lashley-type brain diagrams, from which the percentage of neocortical destruction was estimated by a procedure similar to that described by Lashley (1929). Subsequently, each brain was blocked, frozen, and sectioned frontally at 90 μ . Every fourth section through the lesion was retained and later photographed at 12 $\times$ by using the section as a negative film in an enlarger.

RESULTS

Mortality Rate and Discarded Subjects

Of the original 75 weanling male rats undergoing surgery, 12 died prior to the onset of preliminary training on the detour problems and an additional 8 died during the course of the experiment. The highest mortality rate

occurred in Group GP. Twelve animals were excluded from the experiment because their lesions were either too small, grossly asymmetrical, or distant from the intended target area. All of the remaining 43 brain-damaged and control animals appeared healthy and alert by the end of the 3rd postoperative week, and none was subsequently found to exhibit undue timidity (persistent reluctance to ingest the water or mash rewards) on the appetitively motivated tasks or aberrant escape-avoidance responses (either requiring frequent footshocks to force responses or manifesting "ballistic" running) on the aversively motivated tasks.

Histology

The lesions sustained by the rats in Groups PC (the estimated extent of neocortical damage averaged 25% with a range of 20%–32%) and MR were roughly comparable in both topography and magnitude to those of the corresponding groups examined earlier, which had exhibited deficient acquisition of all problems making up the learning test battery (Thompson et al., 1986). Group GP, however, received somewhat smaller or less symmetrically placed lesions than had the groups investigated earlier. (The animals in Group GP that failed to survive the rigors of prolonged water deprivation sustained the larger and more symmetrically placed pallidal lesions.) The lesions suffered by Groups H and A were generally as large as those of the groups investigated earlier, which had failed to produce acquisition deficits on all problems composing the learning test battery (Thompson et al., 1986).

Typical lesion placements in the animals of the current study are shown in Figures 2–6.

Body Weight

After a 3-week recovery period, the mean (and range of) body weights of Groups C, PC, GP, MR, H, and A were 154 (133–169), 136 (107–159), 131 (110–152), 141 (112–178), 138 (111–162), and 139 g (116–155 g), respectively. The Kruskal-Wallis one-way analysis of variance was applied to these data; the resulting H of 9.0 fell short of the .05 level of significance.

Acquisition of Detour Problems

Two measures of detour problem-solving behavior were considered: total errors committed on Trial 1 on all three problems and total errors committed on Trials 1–5 on all three problems. Although the latter measure provides an assessment of overall performance on the detour problems, the former was also appraised because it reflects an important feature of intelligent (adaptive) behavior called *response flexibility*—the ability to give up unsuccessful response strategies and to try new ones, until the correct one is found. (It should be noted that Trial 1 provides the purest measure of response flexibility, inasmuch as performance on subsequent trials is contaminated by the memory of the correct and incorrect responses made on the first trial.)

Figure 2. Unstained sections showing a lesion to the parietal cortex in one animal.

Table 1 presents the two sets of error scores for all the groups on the detour problems. Since the Kruskal-Wallis test revealed H s in excess of 16 ($ps < .01$), further comparisons disclosed that all the brain-damaged groups, except Group A, were significantly inferior to the controls with respect to at least one of the two performance measures.

Tests of Inhibition

Activity

Figure 7 shows the day-by-day activity scores for all the groups. An analysis of variance over the 5 days showed that the groups were significantly different [$F(5,37) = 11.26, p < .01$]. Comparisons between each brain-damaged group and the controls disclosed that only Groups MR and PC showed significantly heightened activity across the 5 days ($ps < .01$).

Parenthetically, the mean (and range of) rears displayed by Groups C, PC, GP, MR, H, and A over the 5 days were 69.1 (29–112), 91.0 (51–193), 38.2 (7–78), 31.3 (24–40), 124.5 (61–198), and 64.7 (36–113), respectively. The Kruskal-Wallis test applied to these data revealed an H in excess of 16 ($p < .01$). Separate comparisons disclosed that although Groups GP and MR made significantly fewer rears than the controls, Group H made significantly more rears than the controls ($ps < .05$, Mann-Whitney test).

Figure 3. Unstained sections showing a lesion to the globus pallidus in one animal.

Extinction

First phase (acquisition). Figure 8 depicts the performance of all the groups in acquiring the running response to the goalbox. An analysis of variance over the four acquisition days showed that the groups were not significantly different [$F(5,37) = 1.78, p > .10$], although a day-by-day comparison revealed that they did differ during Day 4 [$F(5,37) = 2.47, p < .05$].

A nonparametric analysis of the data also revealed that the terminal level of performance differed among the groups. The median speed for each subject was calculated over the last five trials of acquisition and the first trial of extinction (Trial 0). The means (and ranges) of these values for Groups C, PC, GP, MR, H, and A were 31.5 (20.3–48.5), 12.9 (3.5–48.5), 20.0 (14.3–31.5), 12.8 (9.0–37.1), 16.6 (8.5–33.2), and 21.7 cm/sec

(15.6–35.0 cm/sec), respectively. The Kruskal-Wallis test yielded an H in excess of 16 ($p < .01$) and further comparisons disclosed that all the brain-damaged groups performed at a significantly lower asymptotic level than the controls ($ps < .05$, Mann-Whitney test).

Second phase (extinction). Because the groups attained differing terminal acquisition levels, it was necessary to adjust extinction scores to allow all extinction curves to begin at the same level. Following the procedure of Wagner (1961), extinction speeds were expressed as the proportion of terminal acquisition speed—each animal's median speed on successive blocks of two extinction trials was divided by its median speed on the last five trials of acquisition and Trial 0 of extinction. The groups means of these proportions as a function of successive blocks of extinction trials are presented in Figure 9.

Figure 4. Unstained sections showing a lesion to the median raphe in one animal.

Figure 5. Unstained sections showing multiple lesions to the dorsal hippocampus in one animal.

An analysis of variance showed a significant group effect [$F(5,37) = 3.43, p < .02$] when the groups were compared over the five blocks of extinction trials. The trial-by-trial comparisons, however, revealed that the groups differed only during Blocks 2, 3, and 5 ($ps < .05$ in each block). When compared to the controls, Groups PC, MR, H, and A, but not Group GP, manifested a delay in extinction training across the five blocks of trials ($ps < .05$).

A separate analysis confirmed the foregoing findings. For each animal, the mean time to reach the goalbox on the last eight extinction trials was calculated. These time scores were subsequently converted into reciprocals in order to make them comparable in direction (the larger the score, the poorer the performance) with scores obtained on the other six tests of inhibition. The means (and ranges) of these values for Groups C, PC, GP, MR, H, and A were .05 (.02-.08), .10 (.02-.25), .08 (.02-.17), .14 (.10-.20), .11 (.03-.17), and .10 (.06-.25), respectively. Although all brain-damaged groups tended to run faster than the controls on the last eight extinction trials (note that these groups ran slower than the controls during acquisition), only Groups PC, MR, H, and A showed

a significant extinction deficit ($ps < .05$, Mann-Whitney test).

Spontaneous Alternation

Figure 10 shows the degree of alternation performance for all groups across the 5-day test period. An analysis of variance revealed that the groups were not significantly different [$F(5,37) = 1.49, p > .20$], although there was a significant interaction effect [$F(20,148) = 1.71, p < .05$]. When a day-by-day analysis was performed, a significant group effect was uncovered for Day 1 only [$F(5,37) = 4.06, p < .01$]. Comparisons between the controls and each brain-damaged group revealed that only Group MR evidenced a significant deficit in alternation performance on Day 1 ($p < .01$).

A nonparametric analysis involving a comparison of the mean number of failures to alternate during the 10 test trials yielded results that were consistent with those mentioned above. Only Group MR failed to alternate responses in the T-maze more frequently than the controls ($p < .05$, Mann-Whitney test).

Go/No-Go Discrimination

Acquisition. Figure 11 shows the learning curves for all groups, performance being based upon the ratio of the

Figure 6. Unstained sections showing a lesion to the amygdaloid complex in one animal.

Table 1
Total Errors Committed on the Detour Problems
for All Groups

Group	N	Trial 1		Trials 1-5	
		Errors	Range	Errors	Range
C	10	19.9	7-33	27.5	9-46
PC	9	31.3*	18-46	46.3*	23-70
GP	7	38.3*	25-50	52.4*	39-69
MR	4	50.5*	39-60	108.5*	55-165
H	6	35.5	12-60	63.0*	25-115
A	7	13.1	6-23	19.3	10-29

*Differs from the control group at least at the .05 level (Mann-Whitney test).

median time scores on no-go trials to the median time scores on go trials. The analysis of variance disclosed a significant group effect [$F(5,37) = 3.55, p < .02$] and a significant interaction effect [$F(20,148) = 3.32, p < .01$]. A day-by-day comparison revealed that the groups differed only during Days 4 and 5 ($ps < .01$). Comparisons between each brain-damaged group and the controls revealed that only Groups MR and PC were significantly deficient in mastering this discrimination problem.

Terminal level of performance. Perhaps the best measure of the presence of inhibitory processes in our relatively easy go/no-go discrimination task would lie in performance on the last day of training, when all the animals should have acquired the basic information (rough black floor associated with reward, smooth white floor associated with nonreward) necessary to execute the discriminative response. In this case, the index of performance consisted of the ratio of the mean time score on go trials to the mean time score on no-go trials; this ratio expressed increasing behavioral deficits in terms of increasing ratios. The means (and ranges) of these ratios for Groups C, PC, GP, MR, H, and A were .10 (.05-.18), .52 (.18-.87), .17 (.06-.28), .44 (.33-.50), .14 (.07-.24), and .34 sec (.14-.84 sec), respectively. The Kruskal-Wallis test was applied to these values; the resulting H exceeded 16 and was significant ($p < .01$). Further comparisons disclosed that all the groups apart from Group H were inferior to the controls in withholding a response to the negative cue on the last day of training ($ps < .05$, Mann-Whitney test).

Passive Avoidance

Figure 12 depicts the learning curves for all groups on the "step through" passive avoidance task. The analysis of variance showed that the groups were significantly different [$F(5,37) = 8.39, p < .01$] and that the interaction was significant [$F(20,148) = 3.43, p < .01$], but the day-by-day comparisons revealed that the groups differed only on Days 1, 2, and 4 ($ps < .05$). Comparisons between each experimental group and the controls indicated that only Groups MR, PC, and A were deficient in passive avoidance acquisition ($ps < .05$).

Spatial Reversals

Figure 13 presents the error scores for all groups on original learning (Spatial Reversal 0) and on the four sub-

sequent reversal problems. With respect to original learning scores, the Kruskal-Wallis test yielded an H of 12, which was significant ($p < .05$). Individual group comparisons revealed that only Group MR was significantly inferior to the controls in acquiring the original spatial discrimination problem ($p < .05$, Mann-Whitney test).

An analysis of variance applied to the error scores across the four reversal problems showed that the groups

Figure 7. Activity curves for all groups.

Figure 8. Runway acquisition curves for all groups.

fell slightly short of being significantly different [$F(5,37) = 2.29, p = .06$]. A reversal-by-reversal comparison, however, revealed a significant group effect on Spatial Reversal 1 [$F(5,37) = 3.51, p < .01$] only, and that Groups MR and PC, but not Groups GP, H, or A, were impaired in learning this particular reversal problem ($p < .05$). Parenthetically, if total errors committed on each of the four reversal problems are pooled, then comparisons of the mean scores disclose that Groups MR and PC as well as Group H evidenced a significant deficit in spatial reversal performance ($ps < .05$, Mann-Whitney test).

Figure 9. Extinction curves for all groups.

Figure 10. Spontaneous alternation curves for all groups.

Figure 11. Go/no-go acquisition curves for all groups.

Figure 12. Passive avoidance acquisition curves for all groups.

Visual Reversals

Figure 14 presents the group error scores on original learning (Visual Reversal 0) and on the four subsequent reversal problems. With respect to original learning, the Kruskal-Wallis test revealed an H of 9, which fell short of the .05 level of significance.

The analysis of variance showed a significant group effect [$F(5,37) = 7.72, p < .01$] and a significant inter-

Figure 13. Performance on a series of spatial reversal problems for all groups.

action effect [$F(15,111) = 4.48, p < .01$] when the groups were compared over the four reversal problems. However, the reversal-by-reversal comparisons revealed that the groups differed only on Visual Reversals 1, 2, and 3 ($ps < .05$). Further comparisons disclosed that only Groups MR and PC were significantly deficient in acquiring this series of visual reversal problems ($ps < .05$). Interestingly, Group A was found to be significantly superior to the controls in mastering these problems ($p < .05$). (The same findings were obtained when comparisons were made of pooled errors committed over the four reversal problems.)

Correlational Analyses

Intercorrelations (Pearson product-moment correlation coefficients) among the eight measures of performance (seven separate inhibition scores and the single detour-learning score) are shown in Table 2. In view of the numerous trivial correlations among the inhibition scores, it would appear that our seven tests did not measure the same phenomenon. Detour performance had varying degrees of association with the inhibition scores, but the mean correlation was only .39.

In order to investigate the sources of variance represented by the seven inhibition tests, a key cluster analysis was performed. Two dimensions, accounting for 78% of the variance, were extracted before the clustering algorithm terminated. The factor loading matrix is given in Table 3. It is evident that the two dimensions

are not orthogonal, although there was a modest degree of interrelatedness—the correlation between the two factors was .45, with $p < .01$. As will be discussed later, Factor I may be related to a type of behavioral inhibition that underlies the suppression of a dominant approach-response tendency in the face of nonreinforcement or punishment. Factor II, on the other hand, may be related to a type of behavioral inhibition underlying the suppression of an approach response to the negative cue in an approach-avoidance sensory discrimination situation.

After the factor solution was fixed, the correlation between detour performance and each of the two inhibitory factors was calculated; these values are shown at the bottom of Table 3. It is clear that general learning ability, as assessed by detour performance, is strongly associated with Factor I and more modestly, though significantly, associated with Factor II. A confirmatory principal components factor analysis (Harmon, 1967) resulted in a solution in which the same two factors emerged, accounting for 70% of the variance.

To complete this analysis, standardized T-scores on the two factors were developed (with means of 50 and standard deviations of 10) for each animal, and subsequently the scores were grouped by lesion site. The mean factor scores for each group are given in Table 4. An analysis of variance revealed a significant group effect [$F(5,37) = 14.55, p < .01$], but an insignificant factor effect [$F(1,37) = .59, p > .40$]. However, there was a marginally significant interaction effect [$F(5,37) = 2.43, p = .053$]. Comparisons between each brain-damaged group and the controls disclosed that the animals with parietal or median raphe lesions were significantly deficient on both Factors I and II, those with hippocampal

Figure 14. Performance on a series of visual reversal problems for all groups.

Table 2
Correlations Between Measures of General Learning Ability and Inhibition

Problem	Activity	Extinction	Alternation	Go/No-Go	Passive	Spatial	Visual
Detour	.66†	.41†	.30*	.19	.52†	.28	.43†
Activity							
Extinction	.34*						
Alternation	.55†	.12					
Go/No-go	.25	.06	.07				
Passive	.53†	.25	.21	.32*			
Spatial	.11	.02	.30*	.38*	.29		
Visual	.34*	.08	.34*	.38*	.37*	.69†	

Note—All signs are positive. * $p < .05$; † $p < .01$.

lesions were significantly deficient on Factor I only, and those with pallidal or amygdaloid lesions were not reliably different from the controls.

DISCUSSION

Some Preliminary Comments

If it is granted that one of the distinguishing features of mental retardation is a generalized learning impairment (see Archer, 1987; Thompson et al., 1986), then it can be reasonably argued that Groups PC and MR of the current study were mentally retarded. First, the lesions suffered by the young animals composing these two groups were similar in topography and magnitude to those sustained by the young rats in an earlier experiment that exhibited what appeared to be a generalized learning impairment (Thompson et al., 1986). Second, Groups PC and MR were significantly impaired in learning the detour problems that were introduced at the outset of this study to provide an index of general learning ability. Finally, Groups PC and MR were subsequently found to be sig-

nificantly inferior to the controls in extinction performance and in acquiring the preextinction running response, go/no-go discrimination, passive avoidance response, and both spatial and visual reversal problems.

Unfortunately, the animals of Group GP, which were intended to serve as a third group of brain-injured mentally retarded rats, cannot unequivocally be classed with Groups PC or MR, because their pallidal lesions tended to be smaller (or less symmetrically placed) than those sustained by the young rats in the earlier study that exhibited a generalized learning impairment (see Thompson et al., 1986). However, Group GP was significantly deficient in learning the detour problems and, as a consequence, provided additional data upon which to determine whether learning ability suffers in proportion to the degree of an inhibitory deficit.

As expected from earlier findings (Thompson et al., 1986), the animals of Group H were impaired in learning the detour problems, whereas those of Group A were not. Neither of these groups is to be viewed as being mentally retarded, since lesions of the type sustained by Groups H and A have not been observed to produce a generalized learning impairment (see Thompson et al., 1986).

In an earlier study (Thompson et al., 1985), young rats presumably made mentally retarded by early brain damage were found to be impaired in extinction performance and accordingly were inferred to have an inhibitory defect. However, it was argued that the mere presence of such a defect would not account for a generalized learning impairment, since certain brain-damaged rats that do not exhibit a generalized learning impairment may nevertheless exhibit an inhibitory defect. The results of the current experiment are largely in accord with these conclusions. First, it was demonstrated that the two brain-injured mentally retarded groups in the present study (Groups PC and MR) did indeed suffer from an inhibitory defect, as was evidenced by their exhibiting deficits on at least six of the seven tests of inhibition. However, Group A, which also manifested an inhibitory defect to the extent that it was deficient on three tests of inhibition, not only failed to exhibit a learning disturbance on the detour problems, but also acquired the visual reversal problems significantly faster than the controls. Similarly, Group GP was deficient on only one test of inhibition, yet it committed more errors on the detour problems than did Group PC, which

Table 3
Modified Oblique Factor Loading Matrix

Test	Factor I	Factor II
Activity	.79	
Passive avoidance	.70	.39
Spontaneous alternation	.52	.38
Extinction	.40	
Spatial reversal		.84
Visual reversal	.48	.84
Go/No-go	.38	.45
Detour	.83	.42

Note—All signs are positive, and loadings of less than .25 have been omitted for ease of interpretation.

Table 4
Mean Factor Score Profiles for Each Group

Lesion	T-Scores	
	Factor I	Factor II
Control	42.8	46.2
Parietal cortex	50.6*	57.5*
Globus pallidus	47.0	44.8
Median raphe	73.2*	60.7*
Hippocampus	51.7*	52.9
Amygdala	48.0	42.6

*Differs from the control group at least at the .05 level.

was deficient on six inhibition tests. Further evidence that the degree of the inhibitory defect did not strongly predict the magnitude of the learning impairment comes from the modest, though significant ($p < .01$, one-tailed test), rank-order correlation of .43 between the loss in problem-solving ability (pooled errors on the three detour problems) and the extent of the inhibitory defect (mean rank across the seven inhibition tests) for all 43 subjects. (This correlation compares favorably with the mean product-moment correlation coefficient of .39 between detour performance scores and scores on the seven inhibition tests.)

Two Types of Behavioral Inhibition

Behavioral inhibition has rarely been conceived as a unitary phenomenon. Some of the distinctions that have been made have involved internal versus external inhibition (Pavlov, 1928), reactive versus conditioned inhibition (Hull, 1943), and response versus drive versus stimulus inhibition (Rosvold & Mishkin, 1961). The emergence of two factors derived from the cluster analysis performed on the data of the current study is consistent with the foregoing notions insofar as there may be at least two types of behavioral inhibition.

Loadings on Factor I (represented by hyperactivity and deficiencies on the passive avoidance, spontaneous alternation, and extinction tests) suggest a type of inhibition underlying the suppression of an initial dominant approach-response tendency through habituation, nonreinforcement, or punishment. With respect to the activity test, the dominant response is most likely forward quadrupedal locomotion released by the novel dark enclosure. The dominant responses in the passive avoidance and extinction tests would include approaching the dark compartment and approaching the goalbox, respectively. In the case of the spontaneous alternation test, the dominant response tendency could take the form of a position habit or could even be the same as that involved in the activity test—forward quadrupedal locomotion—in which case uninhibited locomotion might favor responding to the same (preferred) arm of the T-maze over alternating choices.

Loadings on Factor II (represented by poor performance on the spatial reversal, visual reversal, and go/no-go discrimination tests) suggest a more specific type of inhibition underlying suppression of an approach response to a particular feature of the environment (negative cue) in a problem situation where approach to this feature is nonreinforced or punished, whereas approach to another feature of the environment (positive cue) is reinforced. It seems reasonable to suppose that this type of inhibition operates in both original learning and reversal learning, the only major difference between them being that the latter would place a greater demand upon the suppression of the approach response to the negative cue than the former would.

It should be emphasized that the two factors are not entirely independent: the correlation between the two was found to be .45 and highly significant. This may partly be due to the fact that both factors relate to the inhibition of approach-response tendencies. However, there appear to be three important differences between these two factors. First, *Factor I Inhibition* seems to be involved in a context containing no reinforcement for an approach response, whereas *Factor II Inhibition* is involved in a context containing a reinforced (correct) approach response. Second, Factor I Inhibition does not contribute any relevant information to the solution of a problem situation, other than the elimination of a nonadaptive preferred response. On the other hand, Factor II Inhibition, by suppressing an approach response to a negative cue in an approach-avoidance discrimination situation, contributes either information relevant to the location of the reinforcement in a simultaneous discrimination task (the reinforcement is not in the vicinity of the negative cue) or information relevant to the availability of the reinforcement in a go/no-go discrimination task (the reinforcement is temporarily absent when the negative cue is introduced). And third, the contributions of Factor I Inhibition and Factor II Inhibition to learning are not the same over the course of practice. During the initial stage of training, the subject usually displays a preferred approach-response tendency (e.g., position habit) that must be suppressed before learning can take place. Harlow (1950) called these initial approach-response tendencies "error-producing factors." The extinction of these dominant error-producing approach responses, which may require a number of trials to accomplish, would most likely involve Factor I Inhibition. As these dominant response tendencies weaken, Factor II Inhibition could then play a role in the subsequent stages of learning by determining which cues are to be avoided in order to reach the place that contains reinforcement.

Inhibition, Intelligence, and Mental Retardation

A particularly important finding of the current study was that performance on the detour problems, which represents one of the more sensitive measures of global learning ability or g (general intelligence) in the white rat (Crinella et al., 1989), correlated .83 with Factor I Inhibition, but only .42 with Factor II Inhibition, the difference between these correlation coefficients being highly significant ($p < .01$). This raises the possibility that a major component of g in the rat is a Factor I Inhibition, conceivably due to the fact that response flexibility, a key feature of intelligent behavior, is dependent upon the ease with which initial nonadaptive response patterns are abandoned. On the other hand, Factor II Inhibition would appear to constitute a minor component of g , not just because of its involvement in a restricted class of problem-solving activities, but because it would not come into play until the initial dominant response patterns are

suppressed. Stated more concretely, combined performance on activity, passive avoidance, spontaneous alternation, and extinction tests may provide a better estimate of general intelligence in the rat than combined performance on discrimination (spatial, visual, and go/no-go) tests. The literature on animal intelligence and animal models of mental retardation contains little crucial information that bears on this issue. It is interesting, however, that abnormalities on open field activity (Mohammed, Jonsson, Soderberg, & Archer, 1986; Rabe & Haddad, 1972; Vorhees, Fernandez, Dumas, & Haddad, 1984), passive avoidance (Vorhees et al., 1984), spontaneous alternation (Fowler, Hicks, D'Amato, & Beach, 1962), and extinction (Piontkovsky, 1961) tests have been reported in rats rendered microcephalic (and presumably mentally retarded) by prenatal treatment with either methylazoxymethanol or X-irradiation. Although spatial reversal learning impairments are usually observed in these rats (Mohammed et al., 1986; Rabe & Haddad, 1972), visual discrimination learning deficits may (Fowler et al., 1962) or may not (Rabe & Haddad, 1972; Tamaki & Inouye, 1976) occur. It is also interesting that an intensive investigation of the behavior of monkeys, ostensibly made mentally retarded by the experimental induction of phenylketonuria, disclosed that situations in which an initial or learned response pattern had to be suppressed were the ones most likely to differentiate the experimental from the control subjects (Chamove, 1984a, 1984b). This observation is highly suggestive of a Factor I Inhibition deficit in the mentally retarded monkeys.

Curiously, certain learning studies on mentally retarded humans also provide some support for the notion that performance on tests of Factor I Inhibition reflect the level of intelligence more reliably than performance on tests of Factor II Inhibition. For example, there is compelling evidence that extinction of previously learned responses in the context of either classical or operant conditioning is severely impaired in retarded subjects (Denny, 1964; Estes, 1970; Levine, 1975; Lobb & Hardwick, 1976; Mosley, 1975; Mosley, Bakal, & Pilek, 1974). On the other hand, the results derived from studies comparing the retarded with the nonretarded on original and reversal learning of discrimination habits are mixed (see Heal & Johnson, 1970; Umetani et al., 1985; and Zeaman & House, 1967 for a review of some of these studies).

Before this section concludes, it should be recognized that the strong relationship found between Factor I Inhibition and general learning ability in the rat constitutes remarkable empirical support for Stenhouse's (1973) theory concerning the evolution of intelligence. Central to his theory is the *Postponement* or *P-factor*, which relates to the ability (power) to withhold an initially preferred (instinctive) response sequence in the face of nonreinforcement or punishment, thereby providing the opportunity for attempting new response sequences elaborated and shaped by memories of past experience. That his P-factor is comparable in essence to our Factor 1 Inhibition is cap-

tured in the following statement: "It is in the *unlearning* of an already-established habit, however, that the most obvious exercise of the P-factor must be involved" (Stenhouse, 1973, pp. 308-309).

Brain Lesions Affecting the Two Types of Inhibition

As shown in Table 4, Group MR was significantly impaired in Factor 1 Inhibition as well as Factor II Inhibition. The global nature of the inhibitory loss following lesions of the median raphe is not surprising, considering that the serotonergic neurons originating from the raphe nuclei have been generally accepted for several decades as playing a major role in behavioral inhibition (see Soubrié, 1986 for a recent review of this literature).

On the other hand, the finding that Group PC was also significantly deficient in both types of inhibition was completely unexpected. It raises the possibility that poor performance on our battery of seven tests could have arisen from a dysfunction (or set of dysfunctions) independent of that associated with a physiological inhibitory system. It could be speculated that Group PC earned defective scores on six of the seven inhibition tests because of the presence of a generalized intellectual impairment (see Thompson & Yu, 1985). This possibility cannot be ignored when one considers the fact that the various tests of inhibition themselves required a good deal of problem-solving skills. Alternatively, this group's inferior performance could relate to the fact that the parietal cortex of the rat, like that of the human (Critchley, 1966), plays a significant role in visual (Thompson & Yu, 1985), spatial (McDaniel & Thomas, 1978; Thompson, 1983), and tactile (Finger, 1974; Kolb & Walkey, 1987) discriminatory functions, as well as contributes to the ability to orient in space (Kolb & Walkey, 1987). Thus, a loss in the appreciation of visual, tactile, or spatial cues that attends parietal damage could explain the deficits observed on the visual and spatial reversal, go/no-go discrimination, and spontaneous alternation tests. Similarly, a defect in spatial orientation following parietal damage could lie at the basis of the deficits noted on the activity, extinction, and passive avoidance tests.

Interestingly, Group H, which showed a loss only on the extinction and spatial reversal tests, was nevertheless found to be significantly deficient in Factor I Inhibition but not Factor II Inhibition. Group A, in contrast, earned T-scores that were not significantly different from those of the controls in either Factor I or Factor II Inhibition, despite manifesting a loss on the extinction, go/no-go discrimination, and passive avoidance tests. (Group GP also failed to evidence a significant inhibition deficit on either factor.) Relative to the performance of Groups MR and PC, the performances of Groups H and A suggest that neither the hippocampus nor the amygdala can be viewed as serving a global function in the domain of behavioral inhibition. It remains to be seen, however, whether the

impairments on certain tests of inhibition associated with hippocampal or amygdaloid (or pallidal) lesions are products of a focal disorder of central inhibitory mechanisms or secondary consequences of other functional disorders.

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