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Working memory in young rats with lesions to the "general learning system"

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Young rats with certain lesions to the caudatoputamen, globus pallidus, ventrolateral thalamus, substantia nigra, ventral tegmental area, superior colliculus, median raphe, or pontine reticular formation have previously been reported to be deficient in learning a broad range of laboratory tasks. The purpose of the current study was to determine whether young rats with similarly placed lesions (or with dorsal hippocampal lesions) would manifest a working-memory deficit on a variant of a spatial delayed-response task, and whether the degree of any such impairment would correlate with an independent assessment of learning ability (as gauged by performance on a visual-discrimination habit and a series of detour problem-solving tasks). Although all nine brain-damaged groups were inferior to sham-operated controls in acquiring the discrimination and detour problems, only six groups (those with lesions to the caudatoputamen, ventrolateral thalamus, ventral tegmental area, median raphe, pontine reticular formation, and dorsal hippocampus) were significantly impaired in their performance of the working-memory task. All correlations between the various performance scores were positive, but none exceeded .32. These results, together with others obtained from rats with similarly placed subcortical lesions, are discussed in terms of certain cognitive theories of intelligence and mental retardation.

Young albino rats previously subjected to bilateral lesions to certain regions of the caudatoputamen, globus pallidus, ventrolateral thalamus, substantia nigra, ventral tegmental area, superior colliculus, median raphe, or pontine reticular formation have been found to be deficient in learning a wide variety of relatively simple laboratory tasks, including "climbing-detour" problems, visual and nonvisual conventional two-choice discrimination habits, a 3-cul maze, and a series of puzzle-box (latch-box) problems (Thompson, Bjelajac, Heustis, Crinella, & Yu, 1989b; Thompson, Huestis, Crinella, & Yu, 1986, 1987). These findings are especially intriguing when considering the fact that the test battery was of a general nature (the problems were not limited to one sense modality, to one class of laboratory tasks, or to one motivational state), only eight lesion placements (those mentioned above) out of a total of 50 examined to date yielded what appears to be a generalized learning impairment, and all eight structures compose or are anatomically related to the basal ganglia (Heimer, Alheid, & Zaborszky, 1985; McGeer, McGeer, Itagaki, & Mizukawa, 1987). On the basis of these results, the foregoing eight brain regions may be referred to as the *general learning system* (GLS) to distinguish them from the remaining 42 brain regions which apparently have more specific functions in learning. It has further been proposed that young rats bearing lesions to the GLS can be viewed as being mentally retarded, at least to the extent that one of the hallmarks of mental retardation is a generalized learning impairment (Archer, 1987; Denny, 1964; Miller, Hale, & Stevenson, 1968; Zeaman & House, 1967). Admittedly, these findings and proposals require further linkage to data.

One of the more important questions posed by the performance of rats with lesions to the GLS concerns the identification of the fundamental cognitive deficit(s) underlying the generalized learning impairment. So far, our attempts to determine whether GLS-lesioned rats share a common deficit in certain categories of cognitive processes, such as inhibition (as indexed by defective performance on extinction, reversal learning, and passive avoidance), attention (as indexed by impaired performance on visual discriminations of increasing difficulty), or short-term memory (as indexed by inferior learning under distributed practice as compared with massed practice) have not met with much success (Thompson, Bjelajac, Huestis, Crinella, & Yu, 1989a; Thompson, Harmon, & Yu, 1985; Thompson et al., 1986). Although some of the GLS-lesioned groups showed inhibitory, attentional, or short-term memory deficits, others did not. Furthermore, it was shown that rats having damage to certain brain structures not included within the GLS nevertheless exhibited deficits in one or more of these cognitive processes.

The aim of the current study was to examine the hypothesis that a working-memory deficit contributes significantly to the generalized learning impairment exhibited by rats with GLS lesions. Although a radial maze would be ideal for the study of working memory (Olton, 1983), certain brain-damaged groups (those with lesions to the

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globus pallidus, substantia nigra, ventral tegmental area, or pontine reticular formation) would probably not survive the prolonged food- or water-deprivation schedules necessary to complete such a study. We therefore chose to examine working memory within the context of a spatial delayed-response type task in a single-unit T-maze adapted for the use of escape-avoidance of mild footshock as a motive. Each trial consisted of a forced run in which the rat was forced to discover which arm was incorrect (associated with footshock) and which was correct (associated with safety) followed, after a delay, by a choice run in which the rat was given a free choice of the two arms. One session of four such trials, in which the position of the correct (an incorrect) arm varied from right to left in a prearranged "random" order, was given each day for 20 days. This task would tap working memory to the extent that the correct arm is changed from one forced run to the next, requiring the animal to remember during the choice run which arms were associated with footshock and safety during the preceding forced run (see Walker & Olton, 1984). A pilot study revealed that normal rats perform on this task at about the 80%-85% level of accuracy.

To determine whether performance on this working-memory task correlates with problem-solving ability, all brain-damaged and sham-operated control animals of this study were tested for acquisition of three climbing-detour problems and a visual-discrimination problem. For comparative purposes, rats with early lesions to the dorsal hippocampus were also investigated. Although rats with these limbic forebrain lesions have not been found to manifest a generalized learning impairment (Thompson et al., 1986), they have been reported to be deficient on working-memory tasks (Olton, 1983; Olton, Becker, & Handelmann, 1979; Walker & Olton, 1984). Thus, the inclusion of this group would provide additional data on the extent to which a working-memory deficit predicts learning impairments on other kinds of tasks.

METHOD

Subjects and Surgery

Weanling (22-24-day-old) male Sprague-Dawley albino rats, 55-65 g, underwent surgery under deep chloral-hydrate anesthesia (400 mg/kg). The lesions in all experimental groups were accomplished electrolytically by passing a constant anodal current of 1.0-2.0 mA for a duration of 5-10 sec through an implanted stainless steel electrode (0.5 mm in diameter) with 0.5-1.0 mm of the tip exposed. One of these groups (Group CAUD) suffered multiple bilateral lesions to the dorsal half of the caudatoputamen (see Thompson et al., 1989b, for details concerning the stereotaxic coordinates used to guide the lesion electrode in all groups); the remaining eight experimental groups received lesions to the globus pallidus (Group PALL), ventrolateral thalamus (Group THAL), substantia nigra (Group NIGRA), ventral tegmental area (Group TEGM), superior colliculus (Group COLL), median raphe (Group RAPHE), pontine reticular formation (Group PONT), or dorsal hippocampus (Group HIPPO). The last group (Group CONTR) served as operated controls, undergoing the same surgical procedures as the experimental groups, save for drilling of the skull and lesioning of the brain.

Throughout the recovery period, the animals were usually housed, 2 or 3 per cage, in medium-size, hanging wire cages containing a constant supply of food pellets and water. During the first postoperative week, a dish of sweetened wet mash was placed daily in each cage to encourage early resumption of food intake. During the third postoperative week, all animals were handled daily for approximately 5 min. During this handling period and the subsequent period of behavioral testing, the experimenters were given no knowledge as to the group to which each subject belonged. The animals were maintained on a 12-h light-dark cycle with lights on at 0600 h, and were trained only during the light phase.

Apparatus

Detour Box

The detour apparatus, the dimensions of which have been reported elsewhere (Thompson, Harmon, & Yu, 1984), 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 the goalbox permitted this apparatus to be used for the presentation of the three climbing-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 upward into the choice chamber to a maximum height of 10.1 cm above the floor (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 mm above the floor (Figure 1, middle panel). Problem C consisted of a partition containing a win-

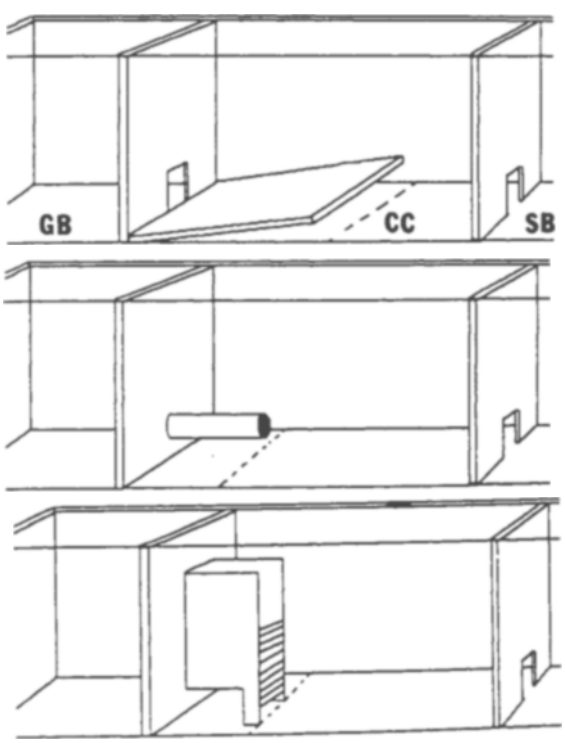

Figure 1. Schematic drawing of the detour apparatus showing the startbox (SB), choice chamber (CC), and goalbox (GB). The interrupted lines mark the boundaries of the "blind alleys." On Problem A (top panel), the rat must mount the raised platform to gain access to the goalbox. On Problems B (middle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

dow 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.) This apparatus was covered by a transparent Plexiglas lid and was located in a sound-attenuated room illuminated by conventional fluorescent ceiling lights.

T-Maze

This single-unit enclosed T-maze was adapted for the use of the motive of escape-avoidance of mild footshock (1.0–1.5 mA). The alleys, which measured 15.2 cm wide and 27.0 cm high, were covered by a transparent Plexiglas lid. The startbox was 34.4 cm long and the arms measured 36.0 cm long. At the end of each arm was a window through which the subject could enter an endbox (28.0×15.2×27.0 cm) by pushing aside a gray card placed against the window. The startbox and the arms of the T had a grid floor, whereas each endbox floor was made of wood. The entire apparatus was located in a sound-attenuated room illuminated by conventional fluorescent ceiling lights.

Visual-Discrimination Apparatus

This apparatus consisted of a 296-liter glass tank measuring 122×42×50 cm filled with tap water (about 20° C) to a depth of 32 cm. It was essentially divided into a start area (29.6×15.7 cm), a choice chamber (55.0×42 cm), and left and right terminal areas, each measuring 31.0 cm long and 19.4 cm wide. The two terminal areas were formed by the presence of a Plexiglas shell painted flat white, which contained a vertical partition and a submerged escape platform that extended 13.0 cm into each terminal area from the rear wall. (A similarly constructed shell painted flat black was used only during preliminary training.) By inserting a Plexiglas plaque (19.4 cm^2) painted flat black at the threshold of the escape platform of either terminal area, this apparatus could be used to establish a white-black discrimination problem; to reach the escape platform, the rat had to avoid the location of the black plaque and approach the location of the white rear wall (see Figure 2).

To prevent the animal from seeing the available escape platform, the water was made opaque by the addition of 25 cc of a liquid whitener (paste food color; Chefmaster, Irvine, CA). The water was routinely cleared of any debris and the tank was cleaned and the water and additive were changed every 5 days.

Located immediately behind the far end of the tank was a drying box (31×46×50 cm) made of smoked Lexan and containing a perforated floor. A blowdryer mounted 36 cm above the floor directed warm air toward the bottom of the box. The entire apparatus was housed in a sound-attenuated room which was illuminated by conventional flourescent ceiling lights.

Wooden Bridges

This apparatus was used to assess balance and motor coordination in all subjects. It consisted of 60.0-cm-long bridges made of birch strips (0.9 cm thick) that varied in width from 1.0–4.0 cm. Each bridge could be clamped to supports 45.7 cm above a padded surface.

Procedure

In all cases, the animals were tested, in succession, on the detour problems, the working-memory problem, the visual-discrimination problem, and, finally, the wooden bridges.

Detour Problems

Following a 3-week recovery period, the animals were deprived of water in their home cages for the duration of this particular learning experiment.

Preliminary training. After 2 days of deprivation, each animal was allowed to explore the entire apparatus (Day 1). A dish of water as well as a dish of sweetened wet mash were available in the goalbox, from which the animal was permitted to ingest for 10 min. On Day 2, the animals (usually run in squads of 2–3) were given 10 preliminary training trials with an intertrial interval of 90–180 sec. Each trial began by placing the animal in the startbox and raising the startbox door. In most instances, 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 restraining cage to await the next trial. On the 10th trial, the animals were usually allowed to ingest the rewards for approximately 200 sec.

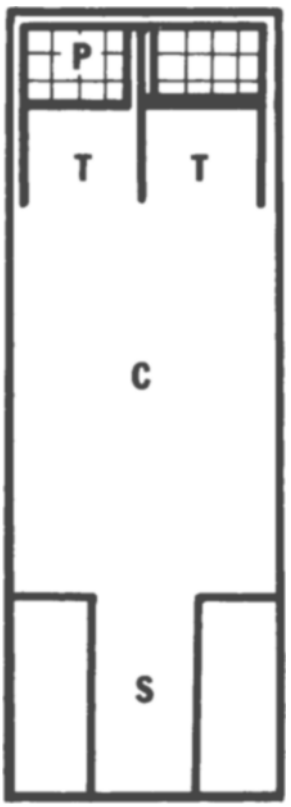

Figure 2. Schematic drawing of the water maze showing the starting area (S), choice area (C), and terminal areas (T). In this drawing, the correct escape platform (P) is on the left side and the black plaque (heavy solid line) is positioned on the right side.

Detour training. Problem A was presented on Day 3, Problem B on Day 4, and Problem C on Day 5. Five trials were given on each problem with an intertrial interval of 90–300 sec. The training procedure was the same as that described in preliminary training.

With respect to Problem A, 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, an error consisted of traversing beyond the opening of the elevated cylinder by at least the length of the animal's body, and an error on Problem C consisted of traversing beyond the ladder by at least the length of the animal's body. Total (initial combined with repetitive) errors were recorded on each trial. Further details of the training procedure have been presented elsewhere (Thompson et al., 1984).

Working Memory

Preliminary training. All rats were first habituated to the left and right endboxes for 5 min and then were immediately trained to run into one of the arms from the startbox, displace the card blocking the window, and enter the endbox to escape from (or avoid)

footshock. Both free and forced choices were given (the latter being accomplished by inserting a barrier at the choice point which blocked one arm of the T) to assure that the animals would receive equal experience with both arms. From 10-20 trials were administered with an intertrial interval of 30-60 sec.

The animals were subsequently given 5 days of preliminary training on the working-memory problems for the purpose of acquainting them with the overall procedure, acclimating them to the receipt of footshocks when encountering a locked card at the end of an arm, and shaping them to make a correction response after commiting an error. The training procedure was identical to that used during the working-memory test.

Working-memory test. Four trials, each consisting of a forced run and a choice run, were given each day for 20 days (5 days of preliminary training and 15 days of formal testing). The delay between the forced run and the choice run was 15 sec and the intertrial interval was held constant at 180 sec. During the forced run, the correct arm was blocked, while the incorrect arm led to a locked card which prevented the animal from entering the endbox on that side. Upon approaching to within 10.8 cm of the locked card, the animal received a mild footshock from the charged grid section. At this moment, the barrier was removed from the correct arm and the animal was forced to choose the correct arm, push aside the unlocked card, and enter the endbox. During the choice run, the animal was free to choose either arm, although it could only gain access to an endbox by responding to the arm that was correct on the immediately preceding forced run. The location of the correct (and incorrect) arm was switched from the right to the left side in a sequence mixed with single- and double-alternation runs.

The specific training procedure was as follows. A forced run was given by placing the animal in the startbox, raising the startbox door, forcing the animal to choose the incorrect arm which led to footshocks (approximately 0.5 sec in duration and with an intershock interval of 1.0-2.0 sec) when the animal stepped on the charged grid section below the locked card, and then forcing the animal to respond to the correct arm, push aside the unlocked card, and enter the endbox. The animal was allowed to remain in the endbox for 5 sec and subsequently was carried to a restraining cage to await the choice run. After 15 sec had elapsed, the animal was placed in the startbox and the startbox door was 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 given unless the animal made an error (approached to within 10.8 cm of the locked card) or failed to respond to one of the cards within 5 sec. The animal was again allowed to remain in the endbox for 5 sec, after which it was carried to the restraining cage. If the animal made a correct response on the first choice run, it was allowed to rest for 180 sec before being given a forced run on the second trial. If, however, an error was made, the animal was given an additional one or more choice runs until a correct response was made. This procedure was adopted to prevent the development of a rigid position habit.

Visual Discrimination

Preliminary training. During this phase of training, a submerged escape platform was available at the far end of both the left and the right terminal areas. A trial was initiated by placing the rat in the start area (facing away from the terminal areas) and was concluded when the animal swam across the choice chamber and mounted one of the escape platforms. The animal was forced to remain on the escape platform for 5 sec and then was transferred to the drying box to await the next trial. Ten trials were usually given, with an intertrial interval of 30-60 sec. On half of the trials, the white Plexiglas shell (which formed the two terminal areas and the escape platforms) was used, whereas a similarly constructed Plexiglas shell painted flat black was used on the remaining trials. Throughout this experiment, the animals were run in squads of 2 or 3.

Discrimination learning. Twenty-four hours later, training was begun on the visual-discrimination problem. An approach response to the terminal area containing the white rear wall led to the escape platform, whereas an approach response to the adjacent terminal area containing the black plaque failed to lead to an escape platform on that side. A block of 16 trials was usually given each day, with an intertrial interval of 30-60 sec. The position of the black plaque was switched from the right to the left terminal area in a sequence mixed with single- and double-alternation runs.

The specific training procedure was as follows. The rat was placed in the start area, facing away from the terminal areas. An error consisted of entering the incorrect terminal area by at least the length of the animal's head and thorax. To escape from the water, the animal had to swim to the correct terminal area where the escape platform was available. After remaining on the platform for 5 sec, the animal was carried to the drying box to await the next trial. Total errors (initial errors combined with intratrial repetitive errors) were recorded on each trial. The criterion of learning consisted of the first appearance of a "perfect" or "near-perfect" run of correct responses having a probability of occurrence of less than .05 (Runnels, Thompson, & Runnels, 1968), followed by at least 75% correct responding in the subsequent block of eight trials given on the next day. The correct terminal area was switched from the left to the right side in a sequence mixed with single- and double-alternation runs. Training was terminated if any animal failed to reach the criterion within 100 trials. In such cases, the error score was treated as though the animal had reached the criterion at the point of termination.

Motor-Coordination Test

Twenty-four hours after training on the discrimination problem, all animals were tested for balance on the wooden bridges. This test involved determining the narrowest bridge upon which the animal could keep its balance for 5 sec. Performance on the 4.0-cm-wide bridge was checked first, followed by performance on the 3.5-, 3.0-, 2.5-, 2.0-, 1.75-, 1.5-, 1.25-, and 1.0-cm-wide bridges. The test was carried out as follows. The animal was placed transversely on the bridge, released, and encouraged to assume a longitudinal position. If the animal succeeded in maintaining its balance during this maneuver on two of three trials, it was then tested on successively narrower bridges. Testing on this series was terminated when the animal failed to reach the criterion on a particular bridge or when the criterion was reached on the 1.0-cm-wide bridge. The score consisted of the narrowest bridge upon which the animal could balance.

This test was repeated 1-3 h later and a mean score was computed for each subject.

Histology

At the conclusion of postoperative testing, which lasted approximately 40-45 days, each brain-damaged rat was killed with an overdose of an anesthetic agent, its vascular system was perfused with 10% Formalin, and the brain was removed and stored in 10% Formalin for 2-4 days. Each brain was blocked, frozen, and sectioned frontally at 90 μ. Every third section through the lesioned area was subsequently photographed at 12× by using the section as a negative film in an enlarger.

Statistical Analysis

The performance measures for the detour, working-memory, and visual-discrimination tasks were, respectively, total errors on all three problems, percentage of correct responses during the 15-day period of testing, and total errors to criterion. One-way ANOVA was used to assess these scores, and intergroup comparisons were made by Student's t test. In case of heterogeneity of variance, as

determined by the Levene F, the pooled variance was used in the calculation of t. Where appropriate, the foregoing analyses were supplemented by nonparametric tests.

RESULTS

Mortality Rate and Discarded Subjects

Of the original 95 weanling male rats undergoing surgery, 13 died prior to the introduction of the detour problems and 1 died during the course of behavioral testing, the highest mortality rate occurring in Groups TEGM and COLL. An additional 17 animals were excluded from the experiment because their lesions were either too small, too large, grossly asymmetrical, or distant from the intended target area. All of the remaining 64 brain-damaged and control subjects (see Table 1 for the group *n*s) appeared healthy, alert, and free from any motor abnormalities.

Histology

The lesions sustained by the various groups in the present experiment were generally found to be similar in locus and magnitude to those received by the corresponding groups investigated in our earlier studies dealing with the neuroanatomy of mental retardation in the rat. (See Thompson et al., 1986, 1987 for photographs of representative lesion placements.) Briefly, Group CAUD suffered damage largely confined to the dorsal half of the caudatoputamen at intermediate levels; Group PALL received lesions restricted to the anterior half of the globus pallidus; Group THAL sustained lesions to the ventrolateral thalamic nucleus which also invaded portions of the anterior, reticular, and centrolateral thalamic nuclei; Group NIGRA suffered lesions to the lateral half of the anterior protions of the substantia nigra which also infringed upon the zona incerta and cerebral peduncle; Group TEGM had lesions which mainly damaged the ventral tegmental area and portions of the posterolateral hypothalamus; Group COLL sustained extensive damage to the superficial and deep layers of the superior colliculus; Group RAPHE received a single midline lesion to the median raphe which extended rostrally to damage portions of the interpeduncular nucleus and overlying linear nucleus; Group PONT suffered damage to the paramedial portions of the pontine reticular formation; and Group HIPPO sustained multiple lesions to the dorsal hippocampus which encroached upon the overlying white matter and subjacent lateral dorsal thalamic nucleus.

Learning Tests

Detour Problems

Table 1 presents pooled total error scores for each group on the three detour tasks. All brain-damaged groups, except Groups THAL and PONT, committed significantly more errors on these tasks than did the controls. It should be noted, however, that the p values associated with Groups THAL and PONT were .06 and .09 (two-tailed tests), respectively. Thus, these data largely agree with earlier findings that performance on the three climbing-detour problems is susceptible to interference by selective lesions to the caudatoputamen, globus pallidus, ventrolateral thalamus, substantia nigra, ventral tegmental area, superior colliculus, median raphe, pontine reticular formation, and dorsal hippocampus (Thompson et al., 1986, 1987). (It should be pointed out that deficient performance on these tasks is not likely due to a motor impairment—we have recently found that young cerebellectomized rats learn these detour problems about as fast as do controls.)

Table 1
Mean Performance Scores on the Working-Memory, Detour, and Visual-Discrimination Problems for All Groups

		Working Memory		Detour		Discrimination	
Group	*n*	PC	Range	Errors	Range	Errors	Range
CONTR	8	81.7	77-92	18.1	13-24	14.3	9-24
CAUD	8	75.2*	65-82	32.3†	18-56	55.9†	33-84
PALL	6	78.1	67-92	61.5†	30-117	77.2†	46-96
THAL	7	70.5*	53-85	30.7	14-47	69.7†	28-92
NIGRA	5	76.3	57-83	43.4†	15-72	54.8†	32-74
TEGM	4	64.6*	53-77	73.3†	42-109	66.8†	28-99
COLL	6	75.6	72-87	67.3†	41-139	30.2†	18-44
RAPHE	4	55.4†	52-58	112.3†	94-141	68.0†	23-99
PONT	8	64.2†	45-73	26.1	17-52	53.9†	26-87
HIPPO	8	69.2†	58-82	52.8†	25-124	46.9†	23-83

Note—PC = percent correct. *Differed from control group, $p < .05$. †Differed from control group, $p < .01$.

Working Memory

As shown in Table 1, mean performance scores on the working-memory test (percentage of correct responses over the last 60 trials) revealed that all groups, except Groups PALL, NIGRA, and COLL, were significantly inferior to the controls. (The finding that Group HIPPO was significantly deficient in the performance of this task can be interpreted as additional evidence that this test measures working memory.)

As noted in Table 2, most of the groups performed somewhat better on the last 20 trials of the working-memory test than on the first 20 trials. However, only Group HIPPO evidenced a significant improvement in performance on the last 20 trials. These data also suggest that Groups TEGM, RAPHE, and PONT showed the greatest impairment in working memory to the extent that they were the only groups manifesting significant performance deficits on the first as well as the last 20 trials of the working-memory test.

Visual Discrimination

In terms of total errors to criterion, all brain-damaged groups were significantly impaired in learning the visual discrimination motivated by escape from water (see Table 1). Except for the deficit noted in Group HIPPO, these findings on the acquisition of a white-black discrimination habit are consistent with those of an earlier series of studies (Thompson et al., 1986, 1987). Conceivably,

Table 2
Percentage of Correct Responses on the First Five (Trials 1-20) and Last Five (Trials 41-60) Days of the Working-Memory Test for All Groups

Group	Trials 1-20	Trials 41-60	Difference
CONTR	78.1	83.8	5.7
CAUD	75.5	75.0*	−0.5
PALL	75.0	75.5	0.5
THAL	67.1	75.5	8.4
NIGRA	75.0	77.0	2.0
TEGM	66.2*	67.5*	1.3
COLL	70.0*	77.4	7.4
RAPHE	60.0†	51.2†	−8.8
PONT	62.5†	67.5*	5.0
HIPPO	61.2†	73.8	12.6‡

*Significantly different from controls at or below the .05 level (Mann-Whitney *U* test). †Significantly different from controls at or below the .01 level (Mann-Whitney *U* test). ‡$p < .05$ (Wilcoxon test).

Table 3
Body Weight, Number of Inconsistent Runs on the Discrimination Problem, and Scores (in cm) on the Wooden-Bridge Balancing Test

	Body Weight		Inconsistent Runs		Wooden Bridge	
Group	*M*	Range	*M*	Range	*M*	Range
CONTR	199	174-223	0		1.3	1.0-2.0
CAUD	193	165-221	1.6†	0-4	1.8	1.3-2.8
PALL	164	118-203	2.6†	0-6	2.4*	1.0-4.0
THAL	185	165-196	2.0	0-9	1.4	1.0-3.5
NIGRA	152†	122-169	1.6*	0-4	1.6	1.0-2.1
TEGM	182	138-214	1.8†	0-4	2.0†	1.8-2.5
COLL	176*	155-199	1.2†	0-2	1.7	1.0-2.8
RAPHE	167†	150-182	1.0	0-2	1.8	1.4-2.3
PONT	189	164-200	4.4†	1-9	1.4	1.0-1.8
HIPPO	192	153-215	2.0†	0-5	1.0†	1.0-1.1

*Differed from the control group, $p < .05$ †Differed from the control group, $p < .01$.

our failure to observe a visual-discrimination learning impairment in young rats with dorsal hippocampal lesions in an earlier study (Thompson et al., 1986) may have been due to the use of punishment (footshock) for errors, a condition which was not incorporated within the current experiment.

One other measure of visual-discrimination performance was analyzed since it may reflect either increased distractability or some other deficit in attentional processes (see Yu, Thompson, Huestis, Bjelajac, & Crinella, 1989). This measure has to do with inconsistent responding to the positive stimulus and was quantified in the current study by screening the data sheets of all animals for a run of four consecutive correct responses followed by one or more errors during the precriterion period. Table 3 shows the mean number of inconsistent runs for each group. It will be noted that all groups, except Groups THAL and RAPHE, made significantly more inconsistent runs than did the controls.

Other Observations

Body Weight

Table 3 also shows the mean body weights of all groups at the outset of preliminary training on the detour problems. Only three of the nine brain-damaged groups manifested a significant weight deficiency.

Bridge Test

As shown in Table 3, only two brain-damaged groups were significantly impaired in coordination (balance) on the square-bridge test. Curiously, Group HIPPO was superior to the controls with respect to this test of coordination.

Intercorrelations

Intercorrelations (Pearson product-moment correlation coefficients) between the six measures recorded in this study are shown in Table 4. Despite the relatively small correlation coefficients involved, it is of some importance to note that performance on the working-memory task had a significant degree of association with performance on both the detour and the visual-discrimination tasks (but not with weight or balance measures). This is especially intriguing since different motivational states were involved in the acquisition of the three problem-solving situations, ranging from escape from water to thirst and escape-avoidance of footshock. The significant correlation between the measure of inconsistency (derived from visual-discrimination performance) and working memory is also of interest, but the former was not significantly associated with detour performance.

DISCUSSION

It should also be noted at the outset that the spatial task used in the current experiment to measure working memory differs markedly from certain other spatial tasks, such as the spatial delayed matching-to-sample problem (Roitblat & Harley, 1988; Stanton, Thomas, & Brito, 1984) used for the same purpose. Two major methodological differences include the use of the motive of escape-avoidance of footshock and the opportunity to experience

Table 4
Correlations Between Five Measures

Measure	Detour	Discrimination	Inconsistency	Weight	Balance
Working Memory	.32*	.27*	.41†	−.3	.01
Discrimination	.29*				
Inconsistency	−.06	.42†			
Weight	−.29*	−.38*	−.11		
Balance	.20	.22	−.07		

*$p < .05$. †$p < .01$.

the consequences of responding to both the correct and the incorrect spatial positions on any given forced trial. Nevertheless, the procedure that we used contains two essential features suggestive of a working-memory task; namely, the retained information gained on the forced trial is relevant for only a short period of time and interference levels are high by virtue of the changing stimulus-response associations occurring within a single training session (Olton et al., 1979). Admittedly, however, our working-memory test may be easy relative to other spatial working-memory tests.

It should also be pointed out that although the animals of Group HIPPO evidenced significant impairments on all three learning tasks of the present experiment, the dorsal hippocampus is not viewed by us as a component of the GLS inasmuch as young rats with hippocampal lesions have not been found to be deficient in learning either a visual discrimination or a nonvisual (inclined plane) discrimination motivated by escape-avoidance of footshock (Thompson et al., 1986), nor have they been found to be deficient in learning a series of problem-box (latch-box) tasks motivated by thirst (Thompson et al., 1989b). On the other hand, the caudatoputamen, globus pallidus, ventrolateral thalamus, substantia nigra, ventral tegmental area, superior colliculus, median raphe, and pontine reticular formation are assumed to be components of the GLS because lesion placements within these structures in young rats produce learning impairments on detour, visual- and nonvisual-discrimination, maze, and problem-box tasks (Thompson et al., 1986, 1987, 1989b). The finding of the current study that those groups with lesions to the GLS were slower than the controls in learning both the detour problems motivated by thirst and the white-black discrimination problem motivated by escape from water is consistent with this assumption.

In light of these considerations, the key finding of the present study is that a spatial working-memory deficit does not lie at the basis of a generalized learning impairment in GLS-lesioned rats. This was shown not only by the relatively normal performance of Groups PALL, NIGRA, and COLL on the working-memory test, but by the trivial relationship between working-memory scores and learning scores on the detour and visual-discrimination tasks (the correlation coefficients ranged from .27 to .32). This outcome is not altogether surprising when considering the fact that the dorsal hippocampus is centrally important in working memory in rats (Olton, 1983; Olton et al., 1979; Walker & Olton, 1984), but may be of little importance in the acquisition of certain sensory-discrimination habits (O'Keefe & Nadel, 1978; Thompson et al., 1986) and problem-box tasks (Thompson et al., 1989b).

On the basis of our findings to date, it would appear that the general learning impairment associated with lesions to the GLS in young rats does not arise solely from a defect in response inhibition (Thompson et al., 1989a; Thompson et al., 1985), "voluntary short-term" attentional processes (Thompson et al., 1985), or spatial short-term "reference" memory (Thompson et al., 1986), working memory (current study). This leaves for consideration the possibility that the relatively broad learning impairment manifested by our brain-damaged rats either is a reflection of some combination of elementary cognitive defects or is a secondary consequence of a disturbance in some superordinate ability (e.g., executive functioning) that transcends the components of cognitive processes. What is intriguing about these alternative possibilities is that they overlap with current conflicting views about impaired cognitive functioning in human retardates. Detterman (1987), for example, has argued that mental retardation is the outcome of a deficit in several independent abilities having high centrality. Other investigators (Campione & Brown, 1978; Campione, Brown, Ferrara, Jones, & Steinberg, 1985), in contrast, have proposed that mental retardation arises from an impairment in the ability to transfer learning from one situation to another, and that this impairment in turn is due to defective "executive control."

With respect to our rats with GLS lesions, we are inclined toward the latter "unitary deficit" view for two reasons. First, notwithstanding reports to the contrary (Commins, McNemar, & Stone, 1932; Livesey, 1986; Wahlsten, 1978; Warren, 1977), we have applied correlational and factor analyses to four altogether different sets of data (each set involving learning scores on a different battery of laboratory tasks earned by brain-damaged and control rats) and in every case obtained not only positive intercorrelations among the tasks, but a first (general) factor on which all learning measures had significant positive loadings. These findings, of course, are suggestive of Spearman's "g" or "general intelligence (or learning) factor" to the extent that such phenomena could not have been observed without the presence of a common underlying characteristic tapped to some degree by all tasks (Spearman, 1927). Second, we have recently completed an experiment showing that young rats with GLS lesions, despite "knowing how" to dig, failed to use (transfer) this skill (an ability that depends upon executive functioning) to solve a tunnel-digging detour problem that was readily solved by sham-operated control rats (Thompson et al., in press).

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