Pharmacology Biochemistry & Behavior, Vol. 36, pp. 923–932. © Pergamon Press plc, 1990. Printed in the U.S.A. 0091-3057/90 $3.00 + .00

Learning Abilities of Rats in Multiple T-Mazes of Two Degrees of Complexity Under the Influence of d-Amphetamine

UTE-ANGELIKA JÄNICKE, BERNHARD JÄNICKE, GERT SCHULZE AND HELMUT COPER

Institute of Neuropsychopharmacology, Free University of Berlin
Ulmenallee 30, 1000 Berlin 19, FRG

Received 21 April 1989

JÄNICKE, U.-A., B. JÄNICKE, G. SCHULZE AND H. COPER. *Learning abilities of rats in multiple T-mazes of two degrees of complexity under the influence of d-amphetamine.* PHARMACOL BIOCHEM BEHAV **36**(4) 923–932, 1990.—The effect of d-amphetamine on the learning capacity of male Wistar rats was investigated in multiple T-mazes in two experiments of increasing or decreasing degree of difficulty. Running speed, distance covered and the number of errors were scored to indicate proficiency and success of learning. These parameters, as well as the distribution of errors (goal-directed orientation), correction of errors (situational orientation) and latency at the decision points (discrimination time) were considered to represent cognitive components. The results demonstrated an experiment effect in that the rats showed more difficulty in learning, as exhibited by a slower running speed and more errors, in the maze with successively increasing demands than in the one with decreasing demands. Oral self-administered d-amphetamine in a dosage of 3–4 mg/kg/day or 7–8 mg/kg/day significantly increased the running speed in a dose-dependent manner. By contrast, success of learning and goal-directed orientation decreased. Situational orientation was, however, dose-dependently improved, at least in the experiment with the increasing demand.

Multiple T-maze Rat d-Amphetamine Experiment effect Drug effect Learning behavior

MOST animals are able to adapt to their environment by learning. Multiple tasks place demands on various brain functions such as memory, motivation, vigilance, etc., which are not independent of one another. A maze is often used to experimentally investigate goal-directed learning, i.e., orientation and recognition of spatial structures. The basis for such methods goes back to the beginning of the century (21,22). Mazes are particularly well-suited to experiments with small rodents (e.g., rats), which live in tunnels and are predisposed to creating spatial relationships (11).

Mazes consist of a system of irregularly arranged paths, wherein the goal box cannot be perceived from the start. The task of the animal is to find the shortest path to the exit. There is an optimization process in the course of learning, in which the acquisition and integration of new information, as well as the recognition of the system by the memory, contribute to finding the shortest way to the goal box. On the basis of behavioral changes it is possible to experimentally analyze how the spatial structure of an originally unknown maze is run more precisely with repeated practice and how it can be dealt with most effectively. By changing the maze or using pharmacological means the performance can be even more precisely analyzed and the importance of individual factors (e.g., running speed, number of errors, distance covered, latency) determined.

Strangely enough, there have been very few experiments made concerning the spatial orientation of rats in sequential mazes of varying complexity, e.g., using different numbers of choice points and reverse learning. There is even only limited knowledge about the capacity of continuous exposure to pharmacological agents to influence this performance. Therefore, the aim of this study was to test whether the performance of rats in a maze is influenced by a sequence of patterns of varying complexity (experiment effect), and to investigate whether the stimulant d-amphetamine has a positive effect on the capacity to learn tunnel systems of varying complexity (drug effect).

METHOD

Animals

Ninety-six male Wistar rats with an initial weight of about 180 g were tested (breeder: Hagemann, Bösingfeld). The animals were housed four per cage with a 12-hour light/dark rhythm (light phase 7 a.m. to 7 p.m.). The room temperature was between 21 and 23°C, the relative humidity was 50 ± 5%.

Materials

Artificial tunnels made of opaque, straight and T-shaped PVC

tubes ($\phi = 8$ cm, thickness = 2 mm) were used. The single elements could be connected in any manner desired so that mazes of various shapes and sizes could be quickly constructed. At the goal box the animal was rewarded with a 10% sugar solution for about 40 sec as positive reinforcement. The animal's change of location within the maze was registered by means of infrared sensors which were installed throughout the maze at intervals of 45 cm. The impulses were recorded by computer and processed with the help of a BASIC program. A 15-cm section of tunnel preceded the first sensor. After an animal entered the maze the entrance was closed with a cap. As soon as the rat went into the goal box with all four feet a gate slid into place to prevent the rat from reentering the maze. At the end of each trial the maze was cleaned with water in order to exclude odor cues.

Procedure

Two experiments (I and II) with 48 rats each were performed. The rats were handled daily for the eight days prior to the experiments. In addition, they were familiarised with the tunnels, the goal box and the sugar solution by running in straight tubes of various lengths during this period. Due to the fact that d-amphetamine has an anorectic effect, the control animals were given only the same amount of feed (Altromin 1320) as the treated rats had received the previous day (pair feeding). In this way the body weight of all the rats could be maintained at about 90% of their initial weight.

Experiment I. The animals had to perform three tasks on five consecutive days each. Twice a day they had to go through a maze with two right-left decisions and then twice through an extended maze with six right-left decisions and finally twice a day through a mirror image version of the latter: 1st task: 2-choice maze for 5 days (L-R); 2nd task: 6-choice maze for 5 days (L-R-R-L-L-R); 3rd task: 6-choice maze mirror image for 5 days (R-L-L-R-R-L); 6-choice maze mirror image for 4 days (withdrawal phase). The correct right-left decisions are shown in parentheses.

Experiment II. In this experiment the rats had to perform the tasks in the reverse order to Experiment I on consecutive days. First they ran through a maze with six right-left decisions, then its mirror image and finally a maze reduced to two decisions. Again, the animals were tested in each task twice a day but this time for six days: 1st task: 6-choice maze for 6 days (R-L-L-R-R-L); 2nd task: 6-choice maze mirror image for 6 days (L-R-R-L-L-R); 3rd task: 2-choice maze for 6 days (L-R); 2-choice maze for 4 days (withdrawal phase).

The number of practice days for tasks 2 and 3 in both experiments are based on pilot experiments with other animals. They showed that in Experiment I 100% (cumulative percentage) of untreated rats required five days to perform the first task free of errors. In Experiment II, where the rats learned a complex maze first, six days were necessary before 75% (cumulative percentage) of untreated animals could successfully complete the first task. In the withdrawal phase of both experiments the rats were tested for four days.

Behavioral Scoring

The following parameters were recorded or calculated to analyze the learning process. It is obvious that there are functional overlaps between the individual parameters:

1. Running speed (cm/sec) (includes running and nonlocomotor activities): Measure of the physical performance.
2. Distance covered (cm) in the single and repeated course run: Measure of efficiency.
3. Errors (entering a blind alley with all four feet): Measure for success of learning.
4. Distribution of errors in relation to the spatial order of the blind alleys: Measure of goal-directed orientation.
5. Correction of an error: Measure of situational orientation.
6. Latency (sec) as "decision time" at the junction: Measure of time-dependent discrimination.

Treatment With d-Amphetamine

The 48 rats in each experiment were divided into three groups of 16 animals. The first group (control) received water ad lib. The second group received d-amphetamine (Knoll Co., Ludwigshafen) in a dose of 3 to 4 mg/kg/day (low dose = LD-group) via drinking water. The third group received the drug in a dose of 7 to 8 mg/kg/day (high dose = HD-group) via drinking water. In order to guarantee the required daily dosage the concentration of d-amphetamine solution was adjusted every day on the basis of the previous day's consumption. The application via drinking water is not stressful for the animal and the procedure has been established in previous investigations which have shown a good relationship between the amount of drug consumed and the respective blood level (12).

To test the extent to which withdrawal of the d-amphetamine affected the performance of the animals the substance was replaced by water on the 6th and 7th days of the third task of Experiments I and II, respectively. The behavior of the rats was then observed for another four days.

Statistics

The results of the two runs on the same day were combined in the figures because they were not statistically significantly different from one another. The hypothesis that the order of the pattern (Experiment I vs. Experiment II) determines the learning (running speed, distance covered, number of errors) of the rats (experiment effect), was tested using one-way analysis (ANOVA). The portion of the variance in the rats' learning behavior contributed to by factors of the experiment and treatment were tested using two-way analysis of variance. The data were also statistically analyzed with respect to interdependences (drug effect). The test according to Scheffé was employed for the multiple group comparison. A significance level of $\alpha = 5\%$ (both directions) was accepted for both procedures.

RESULTS

Running Speed

Experiment I. Figure 1 (top) shows that the rats of all three groups increased their running speed considerably in the individual tasks, as well as in the course of the experiment. The control and the LD-group improved from 6 cm/sec and 7 cm/sec, respectively, on the first day in the 2-choice maze to 27 cm/sec and 25 cm/sec, respectively, at the end of the experiment. At the latter speed they appeared to have attained their maximum value.

The rats of the HD-group were also always the first to reach the goal in all three tasks ($p<0.05$). They increased their running speed from 9 cm/sec at the beginning of the experiment to 36 cm/sec on the final day in the 6-choice maze mirror image. It is interesting to note that the running speed of the HD-group on the first day of the withdrawal phase was considerably lower (24 cm/sec) than on the last day of the 6-choice maze mirror image. This reduction is statistically significant ($p<0.05$).

Experiment II. When the rats learned the complex mazes with 6 decisions first (Fig. 1, bottom) and then the 2-choice maze, an

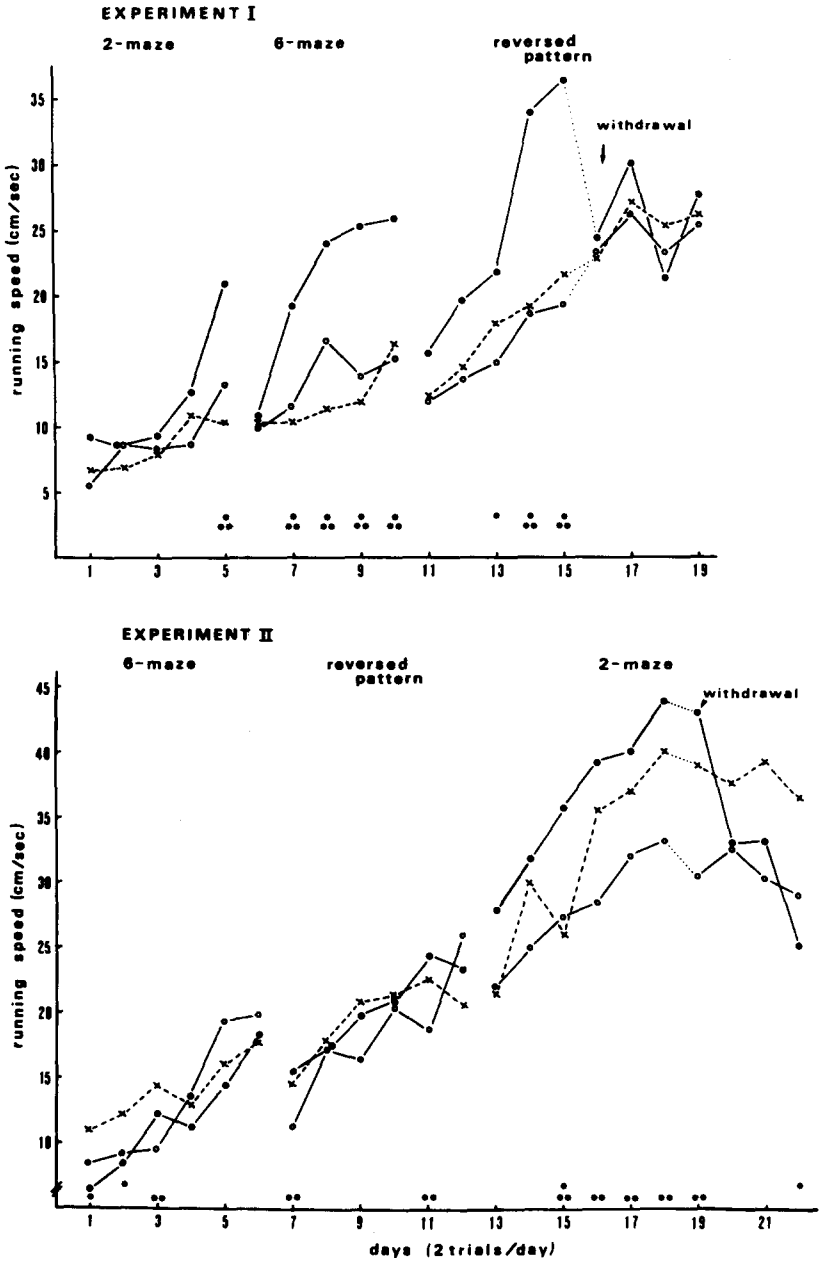

FIG. 1. Running speed (mean values per day) of rats treated with d-amphetamine in comparison to controls in multiple T-mazes. × = control rats; ○ = LD group, ● = HD group. * = control: HD group, ** = LD group: HD group ($p<0.05$ each).

increase in the running speed was observed in the individual groups in all three tasks. In comparison to Experiment I, the controls and LD-group demonstrated a greater increase in running speed in the individual tasks. In contrast to Experiment I the HD-group first attained statistically higher running speeds than the LD-group in the 2-choice maze ($p<0.05$). In the 2-choice maze the controls attained a speed between those of the two treated groups.

On the first day of withdrawal, the HD-group retained, with almost no change, the speed which they had attained in the 2-choice maze. A drastic reduction became apparent only on the following days. The running speed of this group dropped by a total of 40% ($p<0.05$) from the first to the fourth day of withdrawal. The curves of the running speed for the controls and the LD-group in the withdrawal phase flattened out, similar to their behavior in Experiment I. The results clearly show that the ability to move through the maze is not impaired by the treatment but that this physical ability is enhanced by the high dosage of d-amphetamine.

Distance Covered

Experiment I. In the 2-choice maze the direct route to the goal

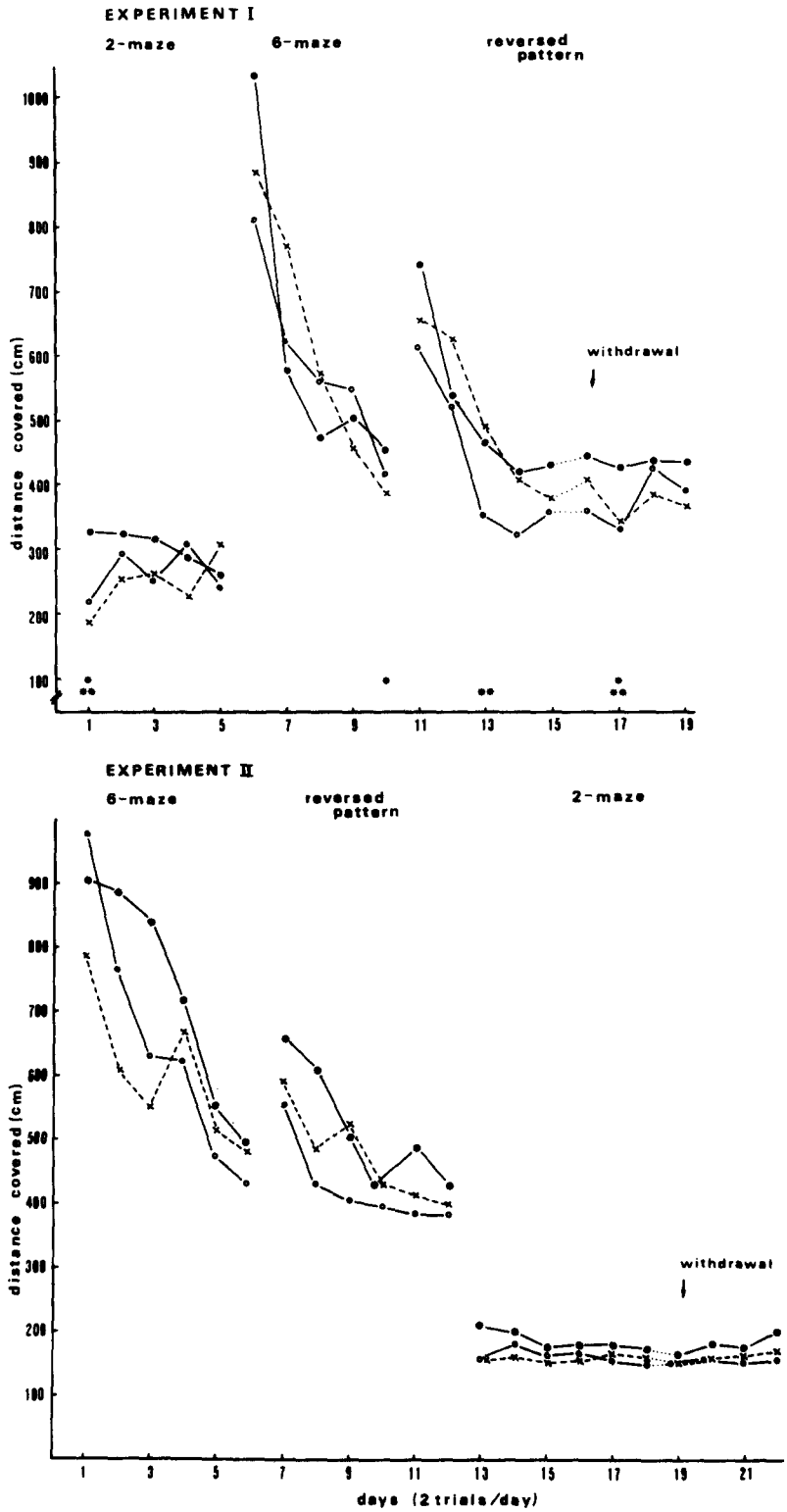

FIG. 2. Distance covered (mean values per day) by rats treated with d-amphetamine in comparison to controls in multiple T-mazes. × = control rats; ○ = LD group; ● = HD group. * = control: HD group, ** = LD group: HD group ($p<0.05$ each).

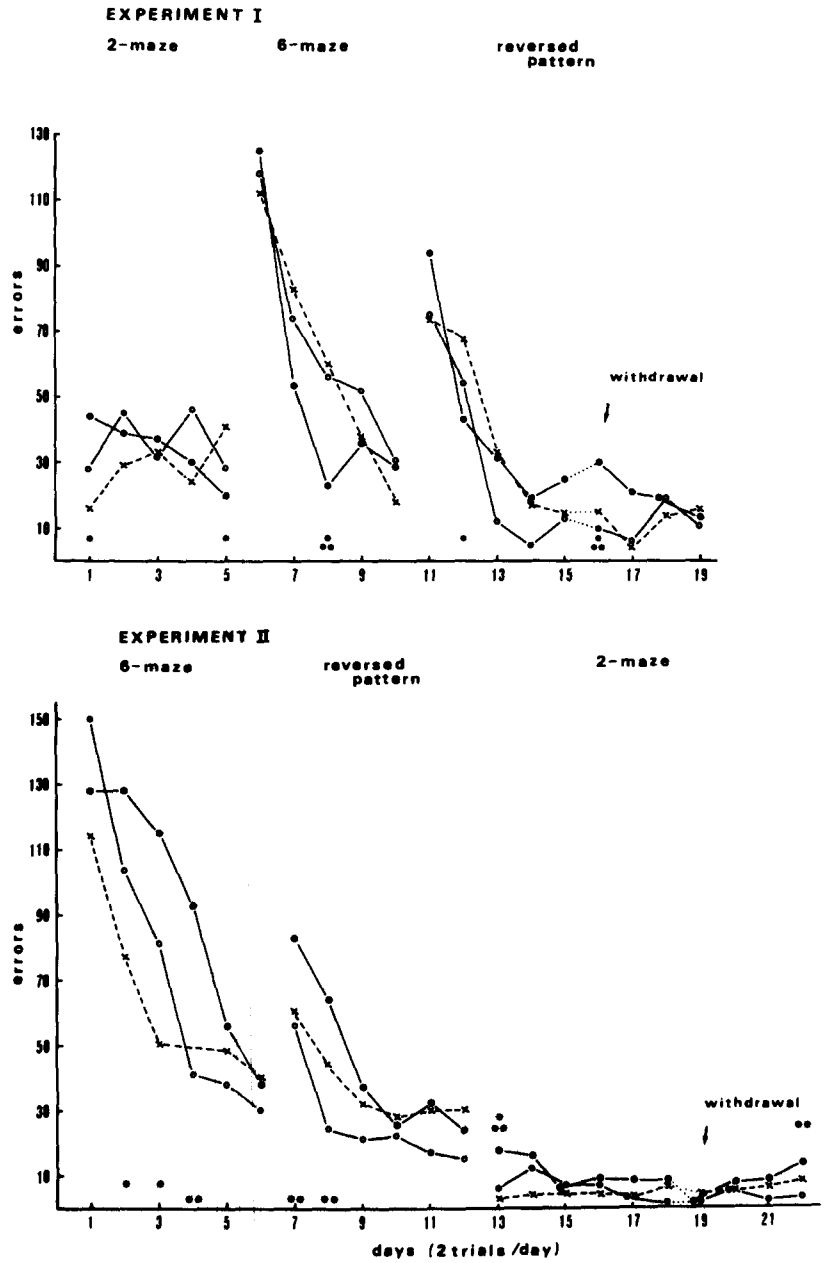

FIG. 3. Frequency of errors (sum per day) by rats treated with d-amphetamine in comparison to controls in multiple T-mazes. × = control rats; ○ = LD group; ● = HD group. * = control: HD group, ** = LD group: HD group ($p<0.05$ each).

box without any errors is 150 cm. The controls ran increasingly longer distances while learning this task from the first (180 cm) to the fifth day (310 cm; Fig. 2, top). The LD-group exhibited indifferent behavior. The distance covered fluctuated between 225 and 310 cm. The HD-group covered a mean distance of 330 cm on the first day. They reduced this distance only slightly (to 265 cm) in the course of the five days. Obviously they ran about aimlessly.

In the 2nd task the direct route was 330 cm. After beginning with mean distances between 810 and 1020 cm, all of the groups had drastically reduced the distance by more than 50% by the fifth day. The HD-group attained a minimum distance of 450 cm on the third day. The controls did not reach this distance until the fourth day and the LD-group did not reach it until the fifth day. This means that d-amphetamine had no significant effect on the distance covered. Similar results were observed for the 6-choice maze mirror image. The initial values of 600–750 cm were considerably lower than with the previous pattern. The rats of the LD-group ran the shortest distance, between 350 and 450 cm, as early as the third day of testing. In the withdrawal phase both the treated rats and the controls continued to follow the shortest distance which they had attained on the last day in the 6-choice maze mirror image.

TABLE 1

FREQUENCY OF ERRORS IN RELATION TO DIRECTIONAL ARRANGEMENT OF CUL-DE-SACS

	Controls		LD-Group		HD-Group	
	Across	Down	Across	Down	Across	Down
2-Choice maze	83	60	118	61	114	56
6-Choice maze	209	102	231	99	163	107
6-Choice maze mirror image	158	49	122	37	151	46
Withdrawal	39	9	35	11	47	37
Subtotal	489	220	506	208	475	246
	(68%)	(31%)	(71%)	(29%)	(66%)	(34%)
Total	709		714		721	
6-Choice maze	248	145	314	144	365	188
6-Choice maze mirror image	172	53	119	36	207	58
2-Choice maze	18	6	27	5	44	16
Withdrawal	11	12	9	3	18	10
Subtotal	449	216	469	188	634	272
	(68%)	(32%)	(71%)	(29%)	(70%)	(30%)
Total	665		657		906	

Experiment II. In Experiment II with 6 decisions the rats of all three groups ran mean distances between 780–970 cm on the first day and thereafter shortened the distance each day (Fig. 2, bottom). In comparison to the other groups, the HD-group exhibited a delayed reduction of the distance covered. In mastering the mirror image pattern the distance covered by the LD-group throughout the experiment was shorter than for the other two groups. In contrast to Experiment I, almost all of the rats ran the shortest distance in the 2-choice maze. This held true for the withdrawal phase as well.

The efficiency with which the animals mastered the maze is dependent on the task. With continued practice it increased to a certain limit despite greater challenges (Experiment II). This limit was not exceeded by any individual animal. The high d-amphetamine dosage exhibited a negative effect on the animals' proficiency compared to that of the controls and LD-group.

Errors

The error curves show almost parallel courses for the distances covered from start to finish. There is, however, no direct correlation between the number of errors and the distance traversed because the parameter "distance covered" also contains distances traversed without errors.

Experiment I. When the rats' first task was to run through the maze with 2 right-left decisions no learning effect could be determined in the controls and LD-group (Fig. 3, top). On the contrary, the controls went into the blind alleys 16 times on the first day, and the number of errors increased consistently up to 41 on the fifth day. The number of errors made by the LD-group fluctuated daily between 28 and 46 errors. Only the rats of the HD-group reduced the number of errors in the 2-choice maze from 45 on the first day to 20 on the fifth day. The difference in the rate of errors between the HD-group and the controls on the first and fifth days is statistically significant ($p<0.05$).

The number of errors increased drastically on the first day in all groups when the maze was extended to 6 R-L decisions. The rate of errors did, however, fall very quickly in the course of the five days. The rats of the HD-group had reached their lowest number of errors, i.e., 22, as early as the third day. The difference from the other two groups was statistically significant ($p<0.05$). With the mirror image pattern of the 6-choice maze the number of errors on the first day increased again in all the groups. The group treated with 7–8 mg/kg/day made the highest number of errors on the first day, but had a lower number of errors than the controls ($p<0.05$) or the LD-group on the second day. The minimum number of errors in all groups was reached on the fourth day of this task. This was rarely surpassed during the withdrawal phase.

Experiment II. Rapid learning could be seen in terms of a sharp reduction of errors in all three tasks in Experiment II (Fig. 3, bottom). The LD-group, in particular, reduced the number of errors in the 6-choice maze from 150 on the first day to 30 on the last day. The HD-group made the most errors in the first task but improved later on. In the relearning task all of the animals entered the blind alleys increasingly less often. There were no differences in the slopes of the error curves for the three groups. Apparently the so-called "skill stage," at which there is no further evidence of improvement, was reached by all groups on the third day of the second task. In the 2-choice maze the rats continued to reduce the number of errors. The marked difference in behavior in the 2-choice maze between the rats in Experiment I and II is interesting. The original learning of a complex task apparently promotes a better sense of direction in the subsequent learning of a simple system.

The more demanding the task, the greater the increase in the rate of learning with practice, regardless of the order of the tasks. When the first task is difficult (Experiment II), the rate of learning under a high dosage of d-amphetamine is slowed. When the reduction in errors and the increase in error-free runs for each task are compared, it can be seen that the frequency of errors made by the three groups decreases at a higher rate than does the increase in error-free runs. It is interesting that the curves of both of these parameters are exponential for the controls and the LD-group. This phenomenon was not detected for the HD-group. Although the animals of the HD-group reduced the number of errors, consider-

TABLE 2

PERCENTAGE OF RATS CONTINUING THEIR PATH GOALWARDS AFTER HAVING ENTERED ONLY ONE CUL-DE-SAC

	2-Choice Maze	6-Choice Maze	6-Choice Maze Mirror Image	Withdrawal
Controls	31% (11/35)	5% (2/37)	10% (4/40)	10% (2/21)
LD-group	14% (6/44)	2% (1/43)	10% (3/30)	18% (3/17)
HD-group	18% (12/67)	42% (11/26)	40% (17/43)	47% (18/38)
	6-Choice Maze	6-Choice Maze Mirror Image	2-Choice Maze	Withdrawal
Controls	40% (20/50)	65% (40/62)	58% (14/24)	61% (14/23)
LD-group	37% (16/43)	30% (18/61)	33% (9/27)	17% (2/12)
HD-group	9% (3/33)	5% (2/39)	3% (1/31)	0% (– 23)

ably fewer error-free runs were observed. This statement applies to both experiments.

Frequency Distribution of Entries Into Blind Alleys in Relation to Spatial Arrangement

Rats learn a maze from the goal backwards. This was already observed in the earliest experiments with mazes (3, 10, 18). Blind alleys which are located closer to the finish are therefore more often avoided than those at the start. An analysis of the distribution of entries into blind alleys per day confirmed this finding in the present experiment. This behavior is not changed by d-amphetamine. The rats of every group entered blind alleys nearer the start more frequently than those nearer the goal.

To judge goal-directed orientation it is essential to know the spatial arrangement of blind alleys entered. A distinction was made according to the spatial relationship of the dead-ends; those leading away from the goal (180° in opposite direction; down) and those leading perpendicular to the goal (90° from the path; across). Table 1 lists the number of entries into the two types of cul-de-sacs and the total number of entries.

Experiment I and Experiment II. The controls and the treated rats behaved similarly in both experiments. They always entered the cul-de-sacs which were perpendicular to the goal more often than those in the opposite direction to the goal. This was true for all three tasks. The ratio (about 70% to 30%) in both experiments remained the same, independent of the total number of errors. The goal-directed orientation increases with time independently of the complexity of the mazes. There was no change in the performance following the administration of d-amphetamine.

Correction of an Error

By means of an analysis of the frequency with which the rats entered dead-ends in the individual runs, it is possible to determine how many animals ran correctly to the finish after leaving a

TABLE 3

MEDIAN OF LATENCY (SECONDS) PER TASK

		2-Choice Maze	6-Choice Maze	6-Choice Maze Mirror Image	Withdrawal
Runs without errors	controls	8.6	10.4	8.0	6.2
	HD-group	6.7	6.5	5.7	7.0
Runs with errors	controls	13.9	28.1	33.0	29.8
	HD-group	17.6	31.9	24.9	27.8
		6-Choice Maze	6-Choice Maze Mirror Image	2-Choice Maze	Withdrawal
Runs without errors	controls	10.1	7.9	3.4	2.9
	LD-group	11.3	8.6	3.9	4.1
	HD-group	13.5	11.5	1.9	2.4
Runs with errors	controls	31.0	29.1	7.7	8.9
	LD-group	40.2	32.5	7.8	12.4
	HD-group	40.7	24.3	5.8	8.6

TABLE 4
STATISTICAL VALUES OF THE ANOVA

Source	*df*	Mean Square	F Value	*pr*<F
Running speed:				
task effect	1	2104.83	19.92	0.0001
drug effect	2	131.47	1.24	0.28
error	378			
Errors:				
task effect	1	8.93	3.03	0.14
drug effect	2	6.25	1.59	0.20
error	378			
Distance covered:				
task effect	1	242175.74	1.57	0.21
drug effect	2	393522.78	2.55	0.07
error	378			

dead-end and how many returned to the start. The examination was limited to only the behavior of rats which had entered one dead-end (Table 2). The behavior of the animals which made two or more errors showed similar results and for that reason is not reported here.

Experiment I. It can be seen in Table 2 that in Experiment I 31% of the controls ran directly to the finish after entering a dead-end in the 2-choice maze. For the LD-group this was true for only 14% and for the HD-group 18%. In the 6-choice maze and the 6-choice maze mirror image a considerably higher percentage of the animals in the HD-group continued on the correct route after entering a blind alley. In the withdrawal phase the number of animals from this treatment group which behaved in this way increased to 47%, in contrast to 10% (controls) and 18% (LD-group).

Experiment II. Compared to Experiment I, in Experiment II a considerably higher percentage of the controls reoriented themselves after they had made an error, and then continued to the goal without making further errors. This was true for all the different maze systems in respect of the LD-group and in particular of the HD-group. In contrast to Experiment I, a much higher percentage of the LD-group ran in the direction of the goal after entering a dead-end. The higher dose (HD-group) caused a behavior pattern which was quite different from that of Experiment I; the overall distance the animals covered was longer.

Situational orientation was determined by the task. It drops as the difficulty increases in Experiment I. The high-amphetamine dose, however, improves it considerably. Strangely enough, in Experiment II situational orientation is comparatively good when the initial demands are high. The d-amphetamine had a negative, dose-dependent influence on this factor.

Latency as "Decision Time" at the Junctions

Experiment I. For technical reasons there are no latency values for the LD-group in Experiment I. When the latency value for the error-free runs of the control group is compared to those of the HD-group, it is seen that there is only a slightly shorter drop in the latency time for the treated group than the controls in all three tasks (Table 3).

Shorter latency times were recorded for the controls than the HD-group in runs with errors in the 2-choice maze and the 6-choice maze. The HD-group demonstrated shorter latency times than the controls at the junction in the 6-choice maze mirror image and in the withdrawal phase.

Experiment II. There is a noticeable drop in the latencies in all of the groups in Experiment II compared to Experiment I. Much shorter times were registered in the error-free runs as well as in those with errors. In general, it was again the treated rats which could apparently decide more quickly. Naturally, the ability to discriminate was considerably higher in the error-free runs than in the runs with errors. Furthermore, it is to some extent affected by the task. The d-amphetamine had no statistically significant influence.

Experiment Effect and Drug Effect

An overall comparison of the results of Experiments I and II leads to the following conclusion (Table 4). If learning ability is measured on the basis of the physical component, success of learning or efficiency, there is a definite experiment effect. The running speed was considerably faster in Experiment II with high initial demands than in Experiment I. The number of errors tended to be lower in Experiment II than Experiment I despite the extra day's practice. The distance covered was also shorter in Experiment II than in Experiment I. There was also an experiment effect evident in orientation and latency. If the rats first learned the simple and then the more complex pattern goal-directed orientation improved. Situational orientation, however, deteriorated. The ability to discriminate at the junctions was partially better in Experiment II than in Experiment I.

A drug effect was most evident in the running speed. This was particularly pronounced in tasks with increasing difficulty under the influence of high d-amphetamine doses. The effect was slight when the initial demands were high.

Efficiency and success of learning tended to be negatively influenced by the high dose of d-amphetamine. This amphetamine dose had an ambiguous effect on orientation. Goal-directed orientation tended to be worse, situational orientation better. The stimulant showed no effect on the discrimination time.

DISCUSSION

A basic prerequisite for directed sensorimotoric learning by an individual in a closed maze is the spatial-temporal registration of its own position and the situational recognition of locations. The purpose of this experiment was to study whether the learning behavior of rats is systematic in tests with increasing or decreasing orders of difficulty, and whether this development could be quantitatively measured. The tests were conducted using multiple T-mazes of varying complexity. Futhermore, the experiment was to clarify if, and to what extent, varying dosages of d-amphetamine affect the learning ability of the animals.

The T-tube maze used is to some extent comparable to the 6-arm tunnel maze used by Bättig *et al.* (1, 7, 8). Both systems allowed the testing of the animals in darkness and therefore the exclusion of external stimuli. Rats react less emotionally in a closed maze and are therefore more "successful" than in an open maze (17).

Experiment Effect

As expected, and consistent with the literature (4–6, 9), the rats mastered the tasks required of them in Experiments I and II. All of the rats reached the goal. There have, however, been few studies about which cognitive powers are decisive, i.e., how the goal is reached.

The efficiency or the success of learning by the experimental animals in one and the same task, measured on the number of errors and distance covered, is of course dependent on the order of

the tasks within the training program. When the rats learned the 2-choice maze first, the success of learning and the efficiency were surprisingly low. Maze-experienced animals mastered the same task in Experiment II much better. This means that the discrimination process is simplified by previous experience and promotes stable behavior. This then is an expression of the well-known phenomenon that acquired behavioral patterns can be employed correctly and successfully in new tasks (15).

This observation is in keeping with the hypothesis of latent learning (16). It assumes that during the learning process memories are also stored which are derived not only from the actual learning situation, but contain either more accompanying information or content about principle behavioral strategies. It is also possible to deduce that the 2-choice maze pattern is quite clearly less attractive for rats which have no experience with mazes than for those which have already learned a more complicated one. The poorer performance in the test should therefore be attributable to lower motivation of a stronger, but inadequate, exploration intensity.

Strangely enough, at the beginning, previous experience in the 2-choice maze has little effect on the learning of the subsequent complex task. The rats began with an equally high rate of errors and their efficiency (distance covered) was as low as in the 6-choice maze. The learning objectives were, however, reached more quickly. This expression of better learning following the modification of a maze holds true for the 6-choice maze mirror image in both experiments. The knowledge gained from the 6-choice maze for use in the 6-choice maze mirror image is even more apparent. Transposition is quicker and more effective. The rats made fewer errors and covered less distance in both experiments in the mirror image than in the 6-choice maze in its original orientation. This demonstrates the advantage of previous knowledge. This result indicates a dramatic improvement in goal-directed orientation (above all, in the treated animals), while the situational orientation improved at a better rate in the controls.

A statistically significant experiment effect can be demonstrated on the basis of these results. The patterns with a step-by-step increase in difficulty make quicker learning possible. By contrast, complex tasks at the beginning of a series of experiments are more challenging for the experimental animal and lead to greater accomplishments.

The literature also confirms that those animals which have learned previously have an advantage in subsequent tasks (13,14). Experiments with moles which first ran through a T-maze and then a Y-maze showed that the animals had first of all to adjust themselves to the new maze. The learning appears after the first experiments at a more challenging level and the animals attained a lower rate of error than in the T-maze. In another experiment young rats ran through a six-armed, radial tunnel maze and then its mirror image (14). In the first run of the mirror image the animals made more errors than in the original. Thereafter, however, the animals learned at a much faster rate than in the original test.

Drug Effect

The drug effect was above all a dose-dependent increase in locomotor activity. d-Amphetamine in lower dosages is for the most part ineffective. The higher d-amphetamine dose causes an increase in locomotor activity. This, in turn, is generally found in tests where the difficulty of the tasks increased progressively. This increase in locomotor activity became apparent, however, only in the last task (2-choice maze) in Experiment II. The effect was not, however, accompanied by higher learning success (number of errors) or better efficiency (distance covered). It is assumed that the animals were less confident in the more difficult maze (Experiment II) and that this explains the higher number of errors and the reduced locomotion. The effect of previous experience of learning the 6-choice maze is not impaired by the stimulant at either dosage level.

It is a generally known fact that d-amphetamine causes increased running activity (2, 5, 20, 24). The higher motor activity raises the probability of entering or reentering dead-ends (2, 5, 9). This result appears to be independent of the type of maze and the reward. This claim is, for example, made because performance in a radial maze does not require the rat to seek a particular direction, but rather to seek different paths, independently of their order, from a central starting point (18). In the mazes used here, however, the rats learned to reach a goal. The establishment of the direction in which the goal lay in relation to the starting point explains why the rats repeatedly chose dead-ends in a perpendicular direction to the goal much more often than in comparison to the dead-ends that led in the opposite direction, i.e., away from the goal. In accordance with the experiments by Kumar (16) the present results can be interpreted as showing that the stimulating effect of d-amphetamine hinders the exploratory desire of the rats and weakens latent learning. In the end this makes the process of increasing familiarity with the maze more difficult.

A reduction in learning capacity under a high d-amphetamine dosage in connection with increased locomotion is consistent with the arousal effect of the stimulant, for which a reverse U-shaped dose-effect relation is known. In this way it can influence decisions made by the animal in a time and experiment dependent manner (23). Exogenous stimuli can, on the other hand, modify this effect. If the tasks require not only associative, but also more constructive solutions, i.e., above all modulation of acquired memory content, the balance between increased motor function and increased efficiency of the cognitive powers is lost.

In summary, these results show that use of the multiple T-maze in a series of experiments with increasing and decreasing demands permits learning procedures to be quantitatively described and differentiated on the basis of suitable parameters. Furthermore, the method allows the modulating influence of the stimulant d-amphetamine to be characterized according to specific functions, such as activity and cognition.

REFERENCES

1. Bättig, K. Spontaneous tunnel maze locomotion in rats. In: Zbinden, G.; Cuomo, V.; Racagni, G. and Weiss, B., eds. Application of behavioral pharmacology in toxicology. New York: Raven Press; 1983:15–26.
2. Bruto, V.; Anisman, H. Acute and chronic amphetamine treatment: Differential modification of exploratory behavior in a radial maze. Pharmacol. Biochem. Behav. 19:487–496; 1983.
3. Carr, H. The distribution and elimination of errors in the maze. J. Anim. Behav. 7:145–159; 1917.
4. Dispensa, J.; Barrett, M. E. The effect of amphetamine (benzedrine) sulfate on maze performance of the albino rat. J. Psychol. 11: 397–410; 1941.
5. Eckermann, D. A.; Gordon, W. A.; Edwards, J. D.; MacPhail, R. C.; Gage, M. I. Effects of scopolamine, pentobarbital, and amphetamine on radial arm maze performance in the rat. Pharmacol. Biochem. Behav. 12:595–602; 1980.
6. Ewing, P. L.; Moore, B. M.; Moore, W. T. The effect of amphetamine and related compounds on maze performance of white rats. J. Pharmacol. Exp. Ther. 105:343–348; 1952.
7. FitzGerald, R. E.; Isler, R.; Rosenberg, E.; Oettinger, R.; Bättig, K. Maze patrolling by rats with and without food reward. Anim. Learn. Behav. 13:451–462; 1985.
8. FitzGerald, R. E.; Oettinger, R. Automated recording of rat activity in a 6-arm radial maze for routine evaluation of behaviour in subchronic

toxicity studies. Zentralbl. Bakteriol. Mikrobiol. Hyg. [B] 185:52–54; 1987.
9. FitsGerald, R. E.; Berres, M.; Schaeppi, U. Validation of a radial maze test for assessing learning and memory in rats. Toxicology 49:425–432; 1988.
10. Hull, C. L. The goal gradient hypothesis and maze learning. Psychol. Rev. 39:25–43; 1932.
11. Jander, R. Ein Ansatz zur modernen Elementarbeschreibung der Orientierungshandlung. Z. Tierpsychol. 27:771–778; 1970.
12. Jänicke, U.-A.; Coper, H. (+)-Amphetamine oral 'drug taking behavior' in naive and tolerant rats. Drug Alcohol Depend. 13: 177–189; 1984.
13. Johannesson-Gross, K.; Gross, H. Lernversuche mit Maulwürfen (Talpa europaea L.) unter Anwendung einer speziellen Labyrinthmethode. Z. Saugetier. 47:277–282; 1982.
14. Jucker, M.; Oettinger, R.; Bättig, K. Age-related changes in working and reference memory performance and locomotor activity in the wistar rat. Behav. Neural Biol. 50:24–36; 1988.
15. Kallenbach, K. Dimensionen des Lernerfolgs beim Labyrinthlernen. Verlag für Psychologie, Toronto: Göttingen; 1979:59–129.
16. Kumar, R. Exploration and latent learning: Differential effects of dexamphetamine and components of exploratory behaviour in rats. Psychopharmacologia 16:54–72; 1969.
17. Lester, D. Effects of habituation to fear on the exploratory behaviour of rats. Nature 220:932; 1968.
18. Olton, D. S. The radial maze as a tool in behavioral pharmacology. Physiol. Behav. 40:793–797; 1987.
19. Peterson, J. Frequency and recency factors in maze learning by white rats. J. Anim. Behav. 7:338–364; 1917.
20. Schlatter, J.; Bättig, K. Differential effects of nicotine and amphetamine on locomotor acitivity and maze exploration in two rat lines. Psychopharmacology (Berlin) 64:155–161; 1979.
21. Small, W. S. An experimental study of the mental process of the rat I. Am. J. Psychol. 11:13–164; 1900.
22. Small, W. S. An experimental study of the mental process of the rat II. Am. J. Psychol. 12:206–239; 1901.
23. Taylor, K. M.; Snyder, S. H. Differential effects of d- and l-amphetamine on behavior and on catecholamine disposition in dopamine and norepinephrine containing neurons of rat brain. Brain. Res. 28:295–310; 1971.
24. Wray, S. R.; Cowan, A. The behavioural effects of levallorphan, cyprenorphine (M 285) and amphetamine on repeated Y-maze performance in rats. Psychopharmacologia 21:257–267; 1971.