

SPATIAL LEARNING IN SOUTH AMERICAN OPOSSUMS
AND ARMADILLOS*¹

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SUMMARY

This experiment compares spatial learning in the South American opossum (*Didelphis albiventris*) and armadillo (*Chaetophractus villosus*) in a Y-maze. Ss learned to turn to one arm of the maze for food reinforcement. To earn further reinforcements, they had to return to the start-box (after consuming the food) where they were restrained for a fixed intertrial interval. The number of entries to the unbaited arm en route to the goal-box (Ri errors), and in the way back to the start-box (Rf errors) were the dependent measures. Opossums and armadillos did not differ in Ri errors. However, only armadillos mastered the task of returning directly to the start-box after each reinforcement. Moreover, a significant within-session improvement in Rf errors was observed in armadillos, but failed to appear in opossums. Results are discussed in terms of species differences in sensitivity to temporal delays.

A. INTRODUCTION

Marsupials and armadillos belong to mammalian orders that have received little systematic attention from students of animal learning. These animals represent orders of phylogenetically older mammals (35), exhibiting important primitive features in the organization of the nervous system. For example, marsupials show the complete absence of *corpus callosum* (32) and

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a different disposition of the hippocampal commissure with respect to Eutherian mammals (28). Armadillos show a large development of rhinencephalic structures of the brain, such as the olfactory tubercles, and pyriform cortex, associated with a relatively small and smooth neocortex (23, 25, 29). These neurological features and the particular phylogenetical position of these species within the class Mammalia are of major interest for the development of a comparative analysis of learning.

The species used in this research were *Didelphis albiventris*² (Marsupial) and *Chaetophractus villosus* (Edentate). *D. Albiventris* lives in woods and forests of Argentina and other South American countries, making their nests in natural holes of tree trunks or between their external roots. They may also be seen in suburban areas and living within the cities themselves. They are active mainly in the evening and at night, feeding on small rodents, birds, chicken, eggs, fruits, lizards, and frogs (12, 40). In the presence of certain stimuli, such as a sudden noise, or a strong beam of light, they often show the catatonic phenomenon of "feigned death." Their gestation period is about 11 days after which they give birth to seven to 15 young; these move from the vulva to the marsupium where they get attached to the nipples. The neuroanatomical features have already been used in neurophysiological research (1, 3), which, of course, is relevant in Comparative Psychology. They have a clear phase of paradoxical sleep characterized by theta rhythm recorded at the neocortical level (4).

C. villosus is a very strong animal, highly resistant to all kinds of surgery, and heavily armored with a bony carapace with eight movable bands. These armadillos are commonly seen in the Pampas and throughout many areas of Argentina and Uruguay. They are active mainly at night but occasionally they may be seen during the daytime (12, 40). They are powerful diggers and live in burrows usually dug out in open areas. They are best caught on moonlit nights (12). When pursued they swiftly run away, often in search of their burrows and when they are unable to find them, they rapidly dig into the ground (12). The gestation period is about two months long and more than one litter of two newborn per year is produced (40). These animals are an agricultural pest because they burrow extensively in loose farm soil (40). This fact, together with their tasteful flesh, explains why they are systematically hunted by man. They are omnivorous and often eat carrion by digging into dead bodies (12). If undisturbed in the laboratory environment

² The scientific name *Didelphis azarae* (Temminck, 1825) has been recently changed to *Didelphis albiventris* (Lund, 1841) for the white-eared opossum (22).

they usually sleep during a high proportion of the daytime. If the environmental temperature is below 28° Celsius their phase of slow sleep is characterized by the appearance of a tremor that involves the whole body and that disappears during paradoxical sleep (1, 5). This is a physiological feature shared with *Priodontes giganteus*, the largest living armadillo (6). They show a clear phase of paradoxical sleep (5), without penile erection (1). The neuroanatomical features have been a stimulus for using them as an experimental model in neuroanatomy (9) and neurophysiology (2, 7, 8, 17).

As far as we know, there are no reports on spatial learning using the marsupial studied in this experiment although some published studies have used *D. virginiana*, a close relative (24, 30). The opossum learned to localize food in a four-arm maze in which the position of the food was changed to a different alley after the animals achieved a criterion to each one of the four arms (26). Spontaneous alternation in a T-maze was also reported (37), and subsequent research showed it to be dependent upon exploration of novel stimuli (33). In a study of spatial probability learning Doolittle and Weimer (15) found that the opossum maximized its choices in a 70:30 problem toward the arm where reinforcement was located on most of the trials. Friedman and Marshall (16) found progressive improvement in a successive spatial reversal task. Finally, James and Turner (27) reported a successful attempt to train young opossums (60-days-old from the pouch) in finding food in a four-compartment maze.

To the authors' knowledge there have been no reports on spatial learning using armadillos as Ss.

The aim of this research was to study spatial learning in South American opossums and armadillos in a relatively complex training situation in which immediate and delayed reinforcement were contingent upon different classes of responses. There is now considerable evidence that animals can discriminate different amounts of temporal delay of reinforcement. Rats, for example, learn to prefer the shortest of a set of alternative paths in a maze (14, 18, 20, 21). They also prefer the path associated with the shortest temporal delay of reinforcement (11, 13, 31, 39). The strong influence of temporal delays on performance has been additionally demonstrated in studies in which the preference for the immediately rewarded alternative is maintained even when the delayed reward is of larger magnitude (10, 19, 34, 36). These results suggest that under a variety of conditions Eutherian mammals show a tendency to optimize their behavior toward a closer spatial and temporal contiguity with respect to the reinforcer.

The main interest of the present experiment concerns the question of

whether there are species differences in the acquisition of a response that can be used to maximize reinforcement rate. The procedure developed to study the sensitivity of the animals to temporal delays included a series of two nominal responses. First, the animals were required to go from the start-box to the goal-box (one of the arms of a Y-maze) where they received an immediate positive reinforcement. Secondly, they were then required to go back to the start-box. The only consequence of the latter behavior was the opportunity for the initiation of a new trial after a delay of 30 sec. This response permitted the animal to have control over the length of the inter-reinforcement interval and, therefore, its acquisition would presumably reflect a capability to discriminate relatively short interreinforcement intervals.

B. METHOD

1. Subjects

Three adult male opossums (*Didelphis albiventris*), weighing between 1.25 and 2.87 kg, and five adult armadillos (*Chaetophractus villosus*), two males and three females, weighing between 2.87 and 3.82 kg were trained. All the animals were brought from their natural habitats and spent a minimum of two months in laboratory conditions before the experiment began. Animals lived in individual cages where water was continuously available. They were deprived of food to a level of $85 \pm 5\%$ of their free-feeding weights. Animals received additional amounts of Purina dog chow when necessary to keep them at a constant level of deprivation. They were maintained under 12:12 hr light-dark cycle (light from 0800 to 2000).

2. Apparatus

A Y-maze with a start-box separated from the rest by a guillotine door was used. The wooden maze was fully lined with plastic; the ceiling was transparent glass, except that over the start-box the glass was painted black to maintain the animal in darkness during the intertrial interval (ITI). At the end of each arm there was a food container; food was accessible in the correct arm, but inaccessible in the incorrect one. The armadillos received 8 g of Purina dog chow as the reinforcer. Exploratory work indicated that the opossums were best trained with a crude meat-ball reinforcer of about 4 g. The maze was 60 cm high, 40 cm wide, 95 cm long in the leg, 79 cm long in each arm, and 40 cm long in the start-box. It was located in a sound-attenuated room with uniform light, and temperature maintained between 20 and 27° Celsius.

3. Procedure

All sessions were conducted during the afternoon, between 1300 and 1800. During the afternoons animals were not particularly active under laboratory conditions. However, as training began they showed an increasing level of activity and in no case was a session interrupted because of a sleepiness condition of the *S*. Initially, the animals received a 10-min habituation session during which they could freely explore the apparatus; the food containers were absent. The arm opposite to that initially entered during the habituation session was assigned as the correct arm during acquisition. Each daily session consisted of 10 trials with a fixed ITI of 30 sec. At the beginning of the session the animal was placed in the start-box and remained there for 30 sec. After this period, the guillotine door was raised and kept in this position until the trial was over. If the animal chose the correct arm, it was reinforced. If the animal made an incorrect choice, it was allowed to correct itself until the reinforcer was found. Once the animal finished eating the food reinforcer, it was free to move about the maze until it reentered the start-box, whereupon the guillotine door was lowered, the trial was ended, and the ITI began. After the last trial of each session, the animal was kept in the start-box during 30 sec, and then it was moved to its cage.

The following procedure was used to compute errors. Three lines were drawn delineating the choice point area: Two of these lines lead to the arms and the other to the leg of the maze. An error was computed whenever the animal crossed one line leading to an incorrect arm with at least its forelimbs. Errors were classified in two kinds: Those made before entering the correct arm, *Ri*-errors, and those made in returning to the start-box after eating the food, *Rf*-errors. For example, if the animal left the start-box, entered the incorrect arm, got back to the leg, and then entered the correct arm and ate the food, two *Ri*-errors were computed. *Ri* was considered acquired when the animal made no errors in a complete session of 10 trials. A session with no errors or only one in the first half was the learning criterion for *Rf*. In a criterion trial the animal chose the correct arm, ate the food, and returned directly to the start-box.

C. RESULTS

Figure 1 shows the acquisition curve of the initial response, *Ri*, that solved a right-left problem under a correction procedure. As can be seen in the figure, both groups exhibited the same acquisition function and did not differ even in the absolute number of errors during the first four sessions.

In contrast with the results obtained for *Ri*, armadillos and opossums

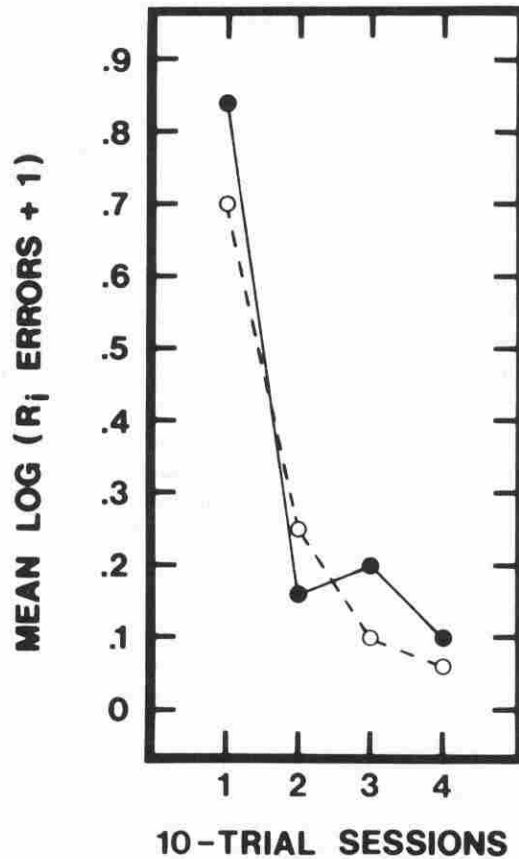


FIGURE 1
MEAN LOG ERRORS AS A FUNCTION OF SESSIONS IN THE OPOSSUMS (FILLED CIRCLES),
AND THE ARMADILLOS (OPEN CIRCLES), SOLVING THE INITIAL RIGHT-LEFT PROBLEM (R_i)

differed in their acquisition of R_f. Figure 2 shows the performance of each animal. Some improvement can be seen at the beginning of the acquisition period in all the opossums, followed by a relatively unchanged performance during 10 sessions for one animal, and 25 sessions for two animals. All the armadillos reached the criterion of a session with no more than one R_f error within the first 10 sessions of acquisition.

The mean trial duration for all the animals is shown in Table 1. This measure gave a similar pattern for both species: Trials were longer during

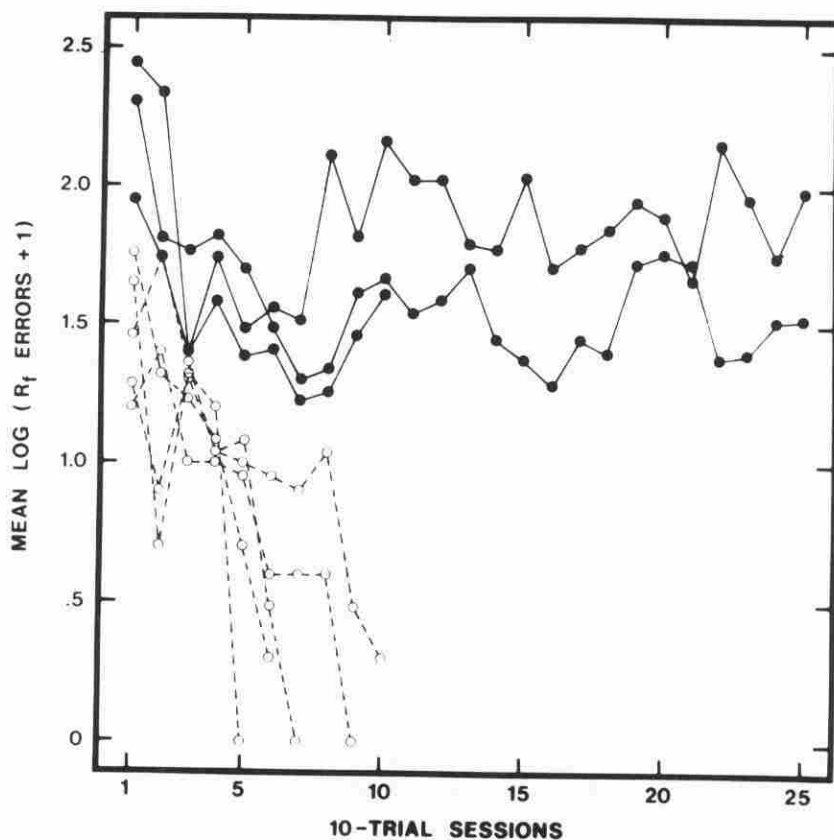


FIGURE 2
MEAN LOG ERRORS OF OPOSSUMS (FILLED CIRCLES), AND ARMADILLOS (OPEN CIRCLES),
IN RETURNING TO THE START-BOX (Rf), AS A FUNCTION OF SESSIONS

the first session than during the last session for all Ss. Therefore, some learning occurred for the opossums even though it did not result in decrements of Rf-errors. Direct observation of the opossum's behavior suggests that no particular activities other than exploration (i.e., grooming, cleaning, etc.) appeared during training that could account for the stability of Rf-errors.

Since all the armadillos reached the criterion in both Ri and Rf, a statistical analysis was performed on the number of sessions to the criterion. A single-factor repeated-measure analysis of variance was used. The result

TABLE 1
Mean Trial Duration (in sec)

Animal	Opossums First	Last	Animal	Armadillos First	Last
1	680.9	58.3(25)	24	363.2	92.4(7)
2	253.7	145.2(10)	27	263.8	147.2(5)
3	364.9	145.0(25)	28	122.2	58.0(9)
			29	300.4	108.7(6)
			30	187.5	118.3(10)
Mean	433.2	116.2		247.4	104.9
SD	221.6	50.1		94.5	32.9

Note: Numbers between parenthesis correspond to the session number of the last session of acquisition.

indicates that animals reached the criterion for Ri significantly faster than for Rf [$F(1, 4) = 81.00$; $p < .001$].

The within-session Rf-errors were analyzed to determine if a consistent pattern occurred between this variable and the acquisition of the Rf behavior. In case of opossums showing a within-session improvement combined with a lack of acquisition across sessions, forgetting during the intersession interval could account for the failure. However, if no improvement is also observed within the session, one could argue that some aspect intrinsic to the task (e.g., long ITI, complexity of the task) was responsible for the failure in exhibiting learning. The mean number of errors in each trial was calculated from the last five sessions of each animal, and a single-factor repeated-measure analysis of variance was performed separately for both groups. The armadillos showed a significant within-session improvement over the last five sessions of each S [$F(9, 36) = 6.42$; $p < .001$]. The opossums showed no significant improvement within the sessions on the last five sessions of each S [$F(9, 18) = 2.20$; $p > .05$].

D. DISCUSSION

This experiment showed that both species behaved similarly when learning to solve a spatial right-left problem with immediate positive reinforcement and correction of errors (see Figure 1). This was so in spite of differences in the interreinforcement period duration produced by the fact that the E had no control over Rf (Table 1 shows that the mean trial duration for the opossum was almost twice as long as for the armadillos during the first session of training), and in spite of differences in the kind of reinforcer (raw meat *versus* Purina dog chow).

The experiment also showed a clear difference between these species with regard to Rf (see Figure 2). While the performance of armadillos was characterized by a slow decrement in Rf-errors until they all reached the criterion, there is no evidence of change in Rf-errors in the opossums, with the exception of the small improvement observed at the very beginning of the acquisition training. However, some evidence that the opossum achieved a considerable degree of adaptation to the experimental situation can be seen in the fact that the trial duration decreased in all the Ss across training sessions (see Table 1). The observation of the Ss indicates that this decrement in trial duration is attributable to an increase in the speed of movement rather than to a decrease in exploration of the maze. This is not consistent with a suggestion advanced by James and Turner (27) who explained the opossum's superiority with respect to the rat in an experiment on spatial learning in terms of less distractibility and less exploratory behavior by the former.

The failure to find a within-session improvement in the opossums suggests that if they learned something during a given trial, the time elapsing to the next trial was sufficient to produce an almost complete forgetting. In other words, species may differ in the degree of sensitivity to the temporal delays present in learning situations. For example, it can be said that armadillos were sensitive to the differences in the interreinforcement period produced by a rapid return to the start-box, thus effectively maximizing reinforcement rate. By contrast, the opossums were not able to link Rf to the initiation of a new trial. Some support for an account of the opossum's failure to master the task in terms of its sensitivity to temporal delays is found in experiments on odor discrimination (38) and reversal learning (16), in the Virginia opossum. These authors found relatively better acquisition when massed, instead of spaced, trials were used. Since it is well-known from the literature that higher mammalian species show better learning under spaced-trial conditions, Tilley *et al.* (38) have suggested the possibility of qualitative differences in memory processes between these two infraclasses of mammals. Additional research is needed in order to determine if opossums can learn Rf under relatively massed practice.

In conclusion, the experimental setting developed for this study was sensitive to species differences in the temporal control of behavior: While opossums and armadillos did not differ in the acquisition of the component of the task reinforced by an immediate consequence (Ri), only the armadillos were capable of learning the component reinforced by a delayed consequence (Rf).

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