Autonomous choice in the learning process of a turtle

Chinemys reevesii

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Abstract

We studied animal’s learning of spatial discrimination in an experimental environment. Turtles, Chinemys reevesii, were employed for the study. We focused on two independent aspects: (1) turtle’s success rate in the task, which is the most common criterion to estimate the ability of the animals, and (2) the statistical properties of the time interval of the task, which is independent on the spatial criterion. For a statistical analysis, we employed the scheme of power law distributions which was recently used to estimate animal behaviors in relation to the idea of the fractal. We addressed the basic problem of whether these two criteria, or any other criteria for this matter, could or could not exclude an observer who studies the animal behavior. To demonstrate inseparability of an observer and the object, we conducted three different learning experiments: (1) complete spatial discrimination, (2) incomplete spatial discrimination, (3) another, different, complete discrimination, in this order. The incomplete one was taken to mean incomplete only for an observer. Our experiments reveal that the same result (success rate) was perceived differently by the animal if the attitude of the observer to the experiments differed. This observation comes to suggest that the notion of autonomous choice on the part of an animal is contingent upon the inseparability between an observer and the object. © 2000 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Autonomous choice; Discrimination learning; Zipf analysis; Power law

1. Introduction

An idea currently prevailing in ethology is that animal learning processes are based on instinct, thus determined by genetic codes, and are subject to stimuli in the animal’s environment (Gould and Marler, 1987). On the other hand, many psychological studies have also been conducted to understand the ability of an animal. In the latter, the issue has been whether the animal can acquire a particular behavior to accomplish a task. The animal behavior has generally been evaluated by referring to the success rate of a given task, such as the decrease of the time interval necessary to achieve the goal. Especially in discrimination learning experiments, scientists evaluate animal behaviors from a spatial point of view, for instance, recording which way an animal took, either left or right.

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In these studies the learning process is considered to be algorithmic, in which an animal is supposed to manipulate some specific codes, either genetic or neuronal. This sort of algorithmic paradigm upon manipulating specific codes, however, does not take into account, the notion of animal autonomy or decision-making property. Earlier behaviorist theories attempted to account for animal behaviors in term of stimulus-response (S-R) associations (Hull, 1943, 1952). Cognitivist initially appealed to the notion of cognitive maps as differing from behaviorist (Tolman, 1948). But recently, like in the notion of ‘place-cell’ in the hippocampus (O’Keefe and Dostrovsky, 1971), both come to hold basically a common framework assuming a one-to-one mapping between an input and an output.

We now want to examine the notion of animal autonomy and the aspect of learning process, as shedding some critical remarks upon such a framework. Our issue will be a critical examination of the role of the observer necessarily introduced into the framework.

One implication of behaviorism is that behavior should be observed as a phenomenon, without making any conjectures about what might be going on within the subject’s mind. It is viewed as a ‘black box’. However, what does matter more in behaviorism is the notion of ‘external observers’ who could definitely observe, describe and encode animal external behaviors. Consider, for instance, the following learning experiment: An observer cannot understand animal’s internal processes in the ‘black box’, but can definitely prepare a problem as an input to an animal and observe the consequential animal behavior, for instance, in terms of success or failure. It implies that the observer knows the answer to the problem, while the animal does not. In other words, the observer can give an animal a problem which is uniquely defined, and ‘the problem’ is not only for the animal but also for the observer. Note that it remains to be seen whether the animal regards the problem set by the observer as an appropriate problem to the animal itself. It is just the idea of anthropomorphism. The external observer who sets the problem and anticipates its a priori unique solution is an anthropomorphic artifact at best.

Despite that, the role of the external observer cannot be wiped out of the study of animal behaviors. Imagine, for instance, an animal put in a maze having no exit. The observer cannot formulate a well-defined problem of learning the incomplete maze to the animal. This observation suggests that we cannot separate the results of learning from the definition of learning, demonstrating inseparability of an observer and an object (Mizukami et al., 1999). If an animal behavior is uniquely encoded by an input-to-output mapping of a one-to-one, critical examination of the role of the external observer would be suspended. This situation is quite resembled to the Frame problem in AI (McCarthy and Hayes, 1969). When one tries to construct a robot which can react to even unknown situations with a one-to-one correspondence scheme, the artifacts originating in the assumption of external observer would become inevitable. Bickhard and Terveen (1996) deal with the fundamental and issues that are intrinsic to encoding in AI and cognitive science. According to their view, encodingism restricts learning by limiting it to the combinatoric space defined by the encoding atoms. It simply means that no new representations are possible, and that the encoding atoms must successfully anticipate all possible contingencies in their space of combinations. However exactly the very reason for what leaning is functionally intended for. There would be no need of learning if anticipation succeeds.

To better grasp the notion of animal autonomy or decision-making, it will be required to clarify the underlying fundamental assumption. Recently, the idea of inseparability of an observer and the object has been attempted in the studies of complex system (e.g. Crutchfield, 1994), endophysics (Rossler, 1987) and internal measurement (e.g. Matsuno, 1989; Gunji, 1995; Gunji and Toyoda, 1997). In addition, some studies on animal behaviors demonstrated a need of new notions and concepts, such as behavioral plasticity (Gunji, 1996), usage of a tool (Kitabayashi et al., 1999), and duality of an attractive and repulsive force in fish schooling behavior (Gunji, 1999). All of these notions emerged from the inseparability of an observer and the object. In the present study reported in this article, we experimented with turtles, *Chinemys reevesii*. 
The animal used in our experiments is commonly called reeves' pond turtles (Family Emydidae). It lives in shallow-freshwater ponds, marshes, or lakes. Its habitat and ecology are reported, for example, in Ernst and Barbour, 1989 and Parmenter and Avery, 1990. The species belonging to this family is used most often in learning experiments (Burghardt, 1977; Macphail, 1982; Suboski, 1992; Papini and Ishida, 1994).

2. Methods

2.1. Experimental strategy

We focused on the working hypothesis that may allow the observer to describe animal behaviors unambiguously in a one-to-one mapping matter. Our objective was to find a framework enabling the observer to describe animal behaviors uniquely. We conducted an incomplete learning experiment in addition to ordinary complete learning experiments. In the incomplete learning experiment, animals were forced to fail or succeed by the observer, whereby the observer cannot distinguish whether the animal actually failed or succeeded. The reason why the observer cannot make such a distinction consists in an ill-suited nature of the problem. We then paid attention to differences in evaluating the same result, that is, differences in the observer’s attitude to those experiments. We first conducted a pre-experiment with turtles, *C. reevesii* that is the ordinary and classical spatial discrimination experiment using the most common apparatus, often called a Yerkes’ discrimination apparatus (Yerkes, 1907). A turtle was put into the experimental box with two lanes, right and left. The one was the correct lane in that the turtle choosing this lane was rewarded with food, and the other was the wrong one in that if chosen the turtle was punished physically. After 100 trials, the turtle tended to choose the correct lane. So the success rate of choosing the correct lane in the latest 8 trials was 100%. We also conducted another experiment, in which the correct lane was changed to the wrong one and vice versa in every trial. The success rate of one turtle over 100 trials was found to be roughly 50%. Actually the turtle gradually stuck to one particular lane and got reward and punishment alternatively. From this experiment, however, we cannot expect any definitive observation on the animal behavior with respect to the ability of learning.

We then tried to unveil the role of the external observer more clearly and reconstructed the notion of animal autonomy or decision-making. For this purpose, we conducted an incomplete experiment.

We attempted three different types of experiments with in the following order: (1) complete-discrimination learning experiment, (2) incomplete-discrimination learning experiment, and (3) another complete-discrimination learning experiment. Experiment (1) and (3) are ordinary experiments in which the observer can definitely identify whether the animal succeeded or failed as practiced in behaviorism. In contrast, the incomplete-discrimination learning experiment was performed in a situation with incomplete experimental conditions, in which the notion of success or failure had no special meaning for estimating the ability of animal behaviors. In this sense, experiment (2) is studied outside the behaviorist’s framework.

2.2. Subjects

We used 17 experimentally naïve turtles (*C. reevesii*) obtained from a commercial dealer in Kobe. Among them, 10 turtles completed all the experiments and were used in the analysis. The turtles measured 21–31 mm in length and 16–24 mm in width. From the date of their arrival to the laboratory till the end of all the experiments, they were all housed in the same tank (60 cm long × 30 cm wide × 35 cm high) made of transparent plastic and filled with water (28–32°C) to a depth of approximately 2 cm. During the day time they were exposed to natural sunlight for approximately one hour per day fed with commercial food for turtles, and the tank was cleaned daily.
2.3. Apparatus

The animals were trained in a $30 \times 33 \times 25$ cm box with a gentle wooden slope of $22.2^\circ$ (training box; Fig. 1). On the upper part of the slope, there were two trapdoors side by side. The slope (including the trapdoors) was $36 \times 30 \times 14.5$ cm wide. Narrow path named the ‘safety path’ (1 cm wide) was arranged between the trapdoors. The slope was covered with a mesh net to provide friction for making the turtles climb easily. The right and left trapdoors were called ‘Trapdoor-R’ and ‘Trapdoor-L’, respectively, and could be opened manually to make an animal fall to the bottom of the training box. The bottom of the training box was covered with a soft mat to reduce physical damage when an animal fell down into the training box.

2.4. Procedure

At the end of a one-month adaptation period, all 17 turtles were put to three different types of experiment.

2.4.1. Complete LR-discrimination learning experiment ('I-R', 'I-L')

The LR-discriminating learning experiment was designed to test if the turtles have an ability to solve alternative problems. First, we decided which Trapdoor would be the correct one, where the turtle could walk through without falling down to the bottom. An individual turtle was first moved to the starting point of the training box (the lower and the central parts of the slope), and left alone. When the correct door was Trapdoor-R, and a turtle climbing up the middle line over Trapdoor-L (Fig. 1), was forced to fall due to opening of Trapdoor-L. The turtle was then immediately moved back to the starting point again. Such a response was called an ‘F’ (false) response. If a turtle climbed up over Trapdoor-R, the trapdoor was not opened. After reaching the top of the slope, the turtle was returned to the home tank for staying there for 3 min and the back to the staring point again. This response was called a ‘T’ (true) one. One trial continued until a turtle climbed up the slope and finished or fell down. If a turtle did not accomplish the task within 30 min, the trial was suspended and was called an ‘S’ trial. The trials for each day ended when the turtle finished with either 10 T responses or 2 S trials. In addition, the maximum duration of the whole experiment per day was 90 min. These trials were named LR-discrimination experiment I-R (the right trapdoor was always opened by the observer). These were performed for all the turtles. The I-R experiment was considered to be completed when the turtle accomplished one of the following two learning conditions: (i) The proportion of T (the total number of correct trials made in a day) was 100%, or (ii) the proportion of T was over 80% for two successive days. After the I-R period was completed, the experiment was switched to I-L (the left trapdoor was opened) on the next day. The difference between the I-L and I-R was the change in the correct door from the right to the left. All the other conditions were kept the same as in the I-R. These two LR-discrimination experiments were carried out for a total of 9 days, and then suspended irrespectively whether or not each experiment was completed.
2.4.2. Incomplete-discrimination experiment ('II-T', 'II-F')

The 10 turtles who finally completed the LR-discrimination experiments were divided into three groups: ‘GroupT’ (intentionally true controlled) \((n = 3)\), ‘GroupF’ (intentionally false controlled) \((n = 4)\), and ‘GroupN’ (non-controlled) \((n = 3)\). The meaning of ‘intentionally true/false controlled’ will be explained below. Each group was tested with three types of problem in different order (Table 1). All experiments started 12 days after the LR-discrimination experiment was finished.

The ‘II-T’ and ‘II-F’ experiments were not discrimination learning experiments. During each experiment, the ‘correct’ trapdoor was not decided in advance, but it was dependent on the turtle’s choice of the way to go. The rate of success (T) per day was scheduled in advance for each experiment, whatever door a turtle chose (R- or L-trapdoor) in each trial. For example, if the rate of T is assigned in advance as 100% (or 0%), a turtle will not be (or will be) made to fall down in the trials, independently of a turtle’s choice of R- or L-trapdoor. This strange experiment conflicts with the fundamental assumption in a discrimination experiment that the ‘correct’ trapdoor must not be altered during the experiment, and can be regarded as an ill-suited experiment with incomplete experimental conditions. In this experiment, T, F and S responses were defined the same as for the first experiment, while in this experiment T (or F) did not imply that an animal chose the correct (or false) answer. Each experiment ‘II-T’ and ‘II-F’ was lasted for 7 days. Table 2 shows the succession of T or F schedule. The proportion of T per day were kept constant for II-T, 77% (10 ‘T’ trials in 13 trials total) in the first 5 days, 91% (10 ‘T’ trials out of 11 trials) in the next 2 days, and 23% for the whole period (7 days) for II-F. All other conditions (for example, the 3 min interval for a finishing a T trial, and no interval for an F trial).

### Table 1
Schedule of experiments

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample (turtle)</th>
<th>Training 1</th>
<th>Interval (days)</th>
<th>Training 2</th>
<th>Interval (days)</th>
<th>Training 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>I-R, I-L</td>
<td>12</td>
<td>II-T</td>
<td>5</td>
<td>III</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>I-R, I-L</td>
<td>12</td>
<td>II-T</td>
<td>5</td>
<td>III</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>I-R</td>
<td>12</td>
<td>II-T</td>
<td>5</td>
<td>III</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>I-R, I-L</td>
<td>12</td>
<td>II-F</td>
<td>5</td>
<td>III</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>I-R, I-L</td>
<td>12</td>
<td>II-F</td>
<td>5</td>
<td>III</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>I-R, I-L</td>
<td>12</td>
<td>II-F</td>
<td>5</td>
<td>III</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>I-R, I-L</td>
<td>12</td>
<td>II-F</td>
<td>5</td>
<td>III</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>I-R, I-L</td>
<td>12</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>I-R, I-L</td>
<td>12</td>
<td>–</td>
<td>–</td>
<td>III</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>I-R, I-L</td>
<td>12</td>
<td>–</td>
<td>–</td>
<td>III</td>
<td></td>
</tr>
</tbody>
</table>

*a Each group of turtles was tested in the order shown. Group N was not tested in Training 2. See text for explanation of differences in training.

### Table 2
The arrangement of ‘T’ and ‘F’ codes in two intentional experiments

<table>
<thead>
<tr>
<th>II-T code</th>
<th>Trial no. (13 or 11 trials per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3  4  5  6  7  8  9  10  11  12  13</td>
</tr>
<tr>
<td>Initial 5 days</td>
<td>T  T  T  T  T  T  F  T  F  T  F  T</td>
</tr>
<tr>
<td>Last 2 days</td>
<td>T  T  T  T  T  T  T  T  F  T</td>
</tr>
<tr>
<td>II-F code</td>
<td>F  F  F  F  F  F  T  F  F  F  T  T</td>
</tr>
</tbody>
</table>

*a T means the animal did not fail wherever it climbed. F means the animal fell into a pitfall intentionally.*
were the same as those in the LR-discrimination experiment. In the II-T experiment, each individual could achieve the learning condition for the LR-discrimination experiment.

2.4.3. Complete-discrimination learning experiment (‘III’ experiment)

The ‘III’ experiment was a different complete discrimination learning experiment lasted for 10 days, but it was more difficult to achieve the correct answer than in the LR-discrimination experiment. We defined the correct behavior only when the turtle climbed up along with the ‘safety path’ and reached the top of the slope. All the other procedures were the same as in the LR-discrimination experiment. The III experiment was started for Group T and Group F 5 days after the ‘II-T’ or ‘II-F’ experiment. The III experiment for Group N was started 12 days after the LR-discrimination experiment (See Table 1).

During all trials in each experiment, the animals were recorded by a video recorder and were observed only on a video monitor. Attention was paid not to disturb them, while they were moved by our hand to the tank or the starting point.

3. Results

In all the trials of each experiment, most turtles tended to start climbing the slope as soon as they were placed to the starting point. Each turtle climbed the slope 464 \( \sim \) 602 times in a whole set of experiments. The number of climbs depended on whether a turtle succeeded in a given trial within a prespecified period. Therefore, the experiment was not completed when an animal continued to fall down through the trapdoors. In all the experiments, the turtles accomplished T or F (sometimes S) responses for each trial. Ten trials were regarded as one ‘block’, and the ratio of T responses in one block was called as the success rate (0.0 \( \sim \) 1.0). The length of each trial (total time) was calculated from the video recordings. The two-dimensional plane of the slope was divided into a grid of squares (5 \( \times \) 6 = 30 squares), and the number of visits to each square a turtle demonstrated (‘steps’) during a trial was counted.

The indicator of the efficiency of climbing the slope is defined by

\[
\text{transition time} = \frac{\text{total time of climbing}}{\text{the number of steps}}.
\]

This means the average time for one step. The transition time decreases as the animal’s speed increases. The faster an individual animal moves, the lower is the transition time.


Ten of the initial 17 individuals achieved at least one of learning conditions, so they seemed to have the ability of solving the alternative-choice problem. The other 7 individuals failed to achieve either conditions. The failed individuals tended to stay at the bottom of the slope, so they were recorded as S many times. The number of turtles that did not achieve the I-L conditions was greater. The LR-discrimination experiment I-L was a reverse learning experiment, because it was made immediately after the I-R experiment. All the turtles had already learned that the left trapdoor was false, which seemed to be the reason for fewer turtles to be successful in I-L. As for the speed of learning (that is, the number of times the turtle climbed up the slope until it learned the correct trapdoor I-R), Turtle 4 was the fastest: only 28 attempts. The other turtles’ speed of learning ranged from 40 to 164 trials.

3.2. Incomplete-discrimination experiment (‘II-T’, ‘II-F’)

We arranged 10 turtles in ascending order, depending on the number of days required to accomplish the II-R experiment. Then we divided them into three groups: Group T (Turtles No 1, 4, 7, 10), Group F (Turtles No 2, 5, 8), Group N (Turtles No 3, 6, 9). Each group contained turtles of all learning speeds to balance the abilities of individual turtles.

The II-T and II-F experiment were not alternative-learning experiments. In II-T, we let the turtles climb up the slope repeatedly without making the turtles fall down through a trapdoor in all the
Fig. 2. Time taken for II experiment. Closed symbols: the individual animals of Group T \((n = 3)\). Open symbols: Group F animals \((n = 4)\).

The major difference between Group T and Group F was in the range of the transition time. Fig. 2 shows the average transition time per block in II-T and II-F. It shows that the individuals in Group F had moved up the slope significantly faster than those in Group T (mean transition time: Group T \(t_T = 15.01 \pm 2.22\), Group F \(t_F = 6.91 \pm 1.41\), \(P < 0.05\)). In Group F the speed of movement, which is the inverse of the transition time in II-F, was approximately seven times the speed in I-R (mean transition time in I-R: Group F \(t_F = 50.07 \pm 27.5\), \(P < 0.05\)). Other significant differences were not observed.

### 3.3. Complete-discrimination experiment (‘III’ experiment)

To judge objectively if an individual turtle had the ability to solve the problem of the third experiment, we divided all trials in experiment III into three successive parts with equal number of trials and counted the number of T responses. Table 3 shows the rate of T trials in each part. In Table 3 ‘Trials’ is the number of all the trials throughout III experiment. We defined the turtle successful and having the ability to solve the conditions of the experiment III if \(\Delta R\) and 3rd-part values were comparatively large (Turtle 1, 3, 5, 6, 8; \(\Delta R = 0.16 \sim 0.36, 3rd\_part = 0.40 \sim 0.58\)). On the contrary, turtles with smaller values of \(\Delta R\) and 3rd-part values were defined as unsuccessful and not able to solve the problem (Turtle 2, 4, 7; \(\Delta R = -0.12 \sim 0.06, 3rd\_part = 0.16 \sim 0.39\)). From estimating the difficulty of III experiment,

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample (turtle)</th>
<th>Trials</th>
<th>1st-part</th>
<th>2nd-part</th>
<th>3rd-part</th>
<th>A R</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>1</td>
<td>234</td>
<td>0.19</td>
<td>0.40</td>
<td>0.55</td>
<td>0.36</td>
<td>success</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>156</td>
<td>0.37</td>
<td>0.31</td>
<td>0.25</td>
<td>-0.12</td>
<td>failure</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>231</td>
<td>0.25</td>
<td>0.48</td>
<td>0.58</td>
<td>0.33</td>
<td>success</td>
</tr>
<tr>
<td>F</td>
<td>4</td>
<td>282</td>
<td>0.33</td>
<td>0.34</td>
<td>0.39</td>
<td>0.06</td>
<td>failure</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>243</td>
<td>0.31</td>
<td>0.37</td>
<td>0.47</td>
<td>0.16</td>
<td>success</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>348</td>
<td>0.15</td>
<td>0.34</td>
<td>0.40</td>
<td>0.25</td>
<td>success</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>396</td>
<td>0.17</td>
<td>0.17</td>
<td>0.16</td>
<td>-0.01</td>
<td>failure</td>
</tr>
</tbody>
</table>

*\(\Delta R\): the change of the rate from 3rd-part to 1st-part.
such a definition might be reasonable. All individuals belonging to Group N fulfilled these success criteria.

Rank × transition time analysis
(power law distribution)

We could not estimate the success rate in II-T and II-F because the success rate in each experiment had no meaning in terms of standard discrimination experiment. To understand what happened to a turtle throughout the series of three kinds of experiments as a whole, we analyzed another aspect of animal’s behavior which does not include the notion of success rate and allows to detect changes in statistical properties of the turtles’ motion, the dependence of the transition time upon its rank.

The values of transition time in each trial were sorted in descending order (rank). For example, the transition time of rank 1 was the longest, that of rank 2 the second longest, and so on. Fig. 3 shows some typical results and fitting lines of the dependencies (1, 2) for the transition time versus rank in double logarithmic plots corresponding to LR-discrimination experiment. For experiments II and III the corresponding plots look similar. The success rate of almost all turtles in the experiment III did not show a smooth curve, and fell down to a low level (between 0 and 10%) at least once in about 100 trials. We divided experiment III into two parts where the success rate first decreased to such a low level, III-fh (the first part of III) and II-sh (the second part of III), and analyzed the dependencies of the rank versus transition time for both parts independently. Table 4 shows the value (M1) of a regression line, calculated from

\[ Y = C_1 \times X^{(M1)} \]  

where \( C_1 \) is a constant, and \( Y \) is the transition time and \( X \) is the rank. Each regression line was calculated by neglecting high ranks. The values in Table 4 in parentheses are not significant because of the low value of square value of a correlation

Table 4
The results of the rank transition time analysis

| Group | Sample (turtle) | Leaning | I-R  | I-L  | II-T | II-F  | III-fh | III-1h | |ΔM1| |
|-------|----------------|---------|------|------|------|-------|--------|--------|-----|-----|
| T     | 1   | Success  | -0.48 | (-0.91) | -0.37 | -0.64 | -0.35 | 0.29 |
|      | 2   | Failure  | 1.54  | -0.47 | -0.47 | -0.49 | -0.47 | 0.02 |
|      | 3   | Success  | -0.45 | -0.59 | -0.26 | -0.24 | 0.35 |
| F     | 4   | Failure  | -1.40 | -0.18 | -0.28 | -0.29 | -0.24 | 0.05 |
|      | 5   | Success  | -0.34 | -0.40 | -0.68 | -0.70 | -0.44 | 0.26 |
|      | 6   | Success  | -0.35 | -0.26 | -0.29 | -0.30 | -0.13 | 0.17 |
|      | 7   | Failure  | 1.54  | -0.14 | -0.04 | -0.05 | -0.06 | 0.02 |

\( |ΔM2| \)
The values accompanied by the symbol \( \# \) show the value (M2) calculated from

\[ Y = C_2 \times e^\Delta (M2 \times X) \]  

(2)

where \( C_2 \) is a constant. The \( |\Delta M1| \) (or \( |\Delta M2| \)) means the absolute value of the difference between the largest and the lowest of M1 (or M2) in II, III-fh and III-sh.

The change of M1 (or M2) is strongly relevant to the results of III experiment. Strictly speaking, the change in M1 (or M2) of the turtles that were defined as ‘failure’ was clearly small (\( |\Delta M1| = 0.02 \sim 0.05, |\Delta M2| = 0.02 \)). In contrast, the change in M1 of the turtles defined as ‘success’ was much larger (\( |\Delta M1| = 0.17 \sim 0.35 \)).

4. Discussion

We extracted the statistical properties of the behavior in each experiment by sorting the transition times of all trials in descending order without making the distinction of whether an animal climbed up the right-hand or left-hand side of the slope. Such way of analysis was first proposed by Zipf (1949) for the statistical approach to linguistic analysis of texts. Generally, fractal dimension \( D \) was calculated from Zipf plots. In our study, \( D \) was the inverse of the slope M1; and most of M1 value for each individual were M1 < 1, and thus \( D > 1 \). According to Mandelbrot (1982), \( D > 1 \) can not be interpreted as fractal dimension, which is only met in cases where a discourse is unnaturally limited by extraneous means (e.g. Latin inserts in a non-Latin text). But, generally speaking, Zipf’s law is emergent in the sense that there are no obvious consequences of the underlying dynamical rules.

Shimada et al. (1995) analyzed the food dwelling time of *Drosophila*, a fly, from the fractal viewpoint. According to their study, the fractal behavior emerges statistically when the animal is placed into a new environment (or a complex situation) that requires complex information processing by the animal. Other behavior expressed by exponential or the Gaussian distribution may indicate rather simple information processing for reflex behavior or after adaptation has been attained.

In the second experiment, the observer cannot decide if a turtle can solve a problem, while the proportion of successes is more than 70%. Only the first and third experiments can be estimated. If no correlation exists between the success of the second and third experiments, then the second experiment is regarded as an erroneous process or perturbation, whether or not the turtle can achieve success in the third experiment. We, however, found that a statistically significant power-law distribution of intermittent walk realized in the second experiment was a key to success in the third experiment. This distribution is independent of the result of the first experiment, that is, the choice of either left or right.

We conclude that a turtle autonomously chooses a particular behavioral pattern independently of external observer’s evaluation in terms of success or false. In other words, we cannot evaluate or encode animal behaviors throughout the whole series of experiments in terms of a one-to-one mapping framework. Our animals had apparently solved the difficult situation of the third experiment, which is beyond the traditional framework of simple behaviorism. Autonomous choice on the part of the animal certainly goes beyond a one-to-one mapping between the input and output.

In summary, the notion of inseparability of an observer and the object entails autonomy of learning and decision-making. What should be rejected is only the one-to-one causal relationship, while causality remains intact. The idea of autonomy is just a dual concept to the mechanical thinking, instead of being something smacking of vitalism.

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