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12. Supported by PHS grants 5 RO 1-HE-01275 and 5 TI-AM-5040.
- 8 February 1965

Probability-Learning by the Turtle

Abstract. *Tested in a two-choice situation, the painted turtle, Chrysemys picta picta, shows random probability-matching in visual problems and in confounded visual-spatial problems, but only maximizing or nonrandom matching (reward-following) in spatial problems. The results are compared with those of analogous experiments on fish, bird, and mammal.*

Given a choice between two stimuli, one of which is rewarded, say, on a random 70 percent of trials and the other rewarded on the remaining trials (a so-called 70:30 problem), a rat or a monkey typically "maximizes" (1)—that is, it comes to choose the more-frequently rewarded stimulus on almost all trials. Occasionally, one of these animals "matches"—that is, its asymptotic choice-ratio approximates the reward-ratio; but the matching is nonrandom—that is, the patterns of choice give evidence of certain simple strategies that are reminiscent of the more complex strategies associated with probability-matching in man. In experiments with the rat (2), for example, matching has been traced to reward-following (a tendency on each trial to choose the alternative rewarded in the previous trial), while the opposite strategy (avoiding the previously rewarded alternative) has been found in experiments with the monkey (3). In experiments with the fish (4), by contrast, matching has appeared which may be characterized as random because the data show no sequential dependency. This difference in results for fish and mammal has led to the study of certain intermediate forms.

In our studies we used 22 experimentally naive, sexually mature painted turtles (width of carapace, about 10 cm) from the laboratory colony. After adaptation to individual 40-liter aquariums, the animals were trained in a black Plexiglas chamber containing about 1.5 cm of water (5). At one end of the chamber were two circular targets of translucent Plexiglas, which were illuminated with colored lamps at the start of each trial. The animal was trained to make a choice by pressing its nose or foot against one or the other of the targets. A correct choice turned off the target lights and caused a pellet of flounder to be rotated into the chamber on a tray at a point just above water and midway between the targets. At the same time, a white light above the point of delivery of the food was turned on for a few seconds to signal the presentation of food and to enable the animal to find it. The animal bit the food from the tray, lowered it into the water, and ate it. After an incorrect choice, the target lights were turned off for 6 seconds of darkness before the two targets were illuminated again. After a predetermined number of repetitive errors, the period of darkness was followed by illumination of the correct target alone (guidance), and the animal was rewarded for pressing it. All of the events of training were programmed automatically, and the responses were recorded on tape.

Each animal had six daily training sessions per week. There were ten trials per session for some animals and 20 trials per session for others, with an interval of 6 seconds (in darkness) between trials. In some instances, guidance followed three repetitive errors; in others, guidance followed the initial error (that is, there was no opportunity for repetitive error). Neither the number of trials per session nor the repetitive-error limit in use seemed to make a difference.

The performance of five turtles trained in 100:0, 70:30, and 50:50 visual problems is plotted in Fig. 1. In these problems, the two targets were illuminated with lamps of different colors on each trial (one red, the other green); the location of each color varied from trial to trial in quasi-random order (6). Three of the animals began with a 100:0 problem (in which choice of one of the colors was rewarded on all trials); they were then shifted to a 50:50 problem (in which

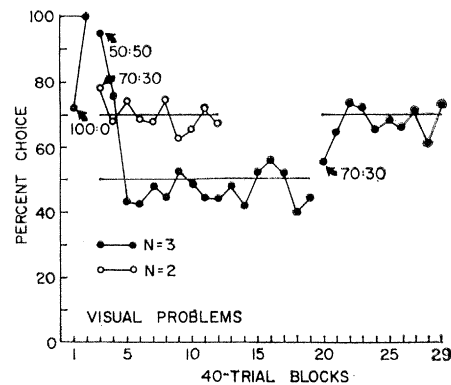


Fig. 1. Performances of five painted turtles in 100:0, 70:30, and 50:50 visual problems. *N*, number of turtles in each group; means of groups are plotted.

each color brought reward on a random half of the trials), and finally shifted to a 70:30 problem (in which the color rewarded on all trials in the first problem was rewarded on a random 70 percent of trials, and the alternative color was rewarded on the remaining trials).

The performance of these animals is plotted in terms of the mean percentage of trials on which the color rewarded 100 percent of the time in the first problem was chosen by the turtle in each stage of training. The other two animals were trained from the outset on the 70:30 problem; their performance is plotted in terms of the mean percentage of trials on which the color rewarded 70 percent of the time was chosen. The correspondence between choice-ratio and reward-ratio evident in the mean curves is characteristic of the individual performances—all the animals showed good matching. The matching, furthermore, appeared to be random. Tests of the

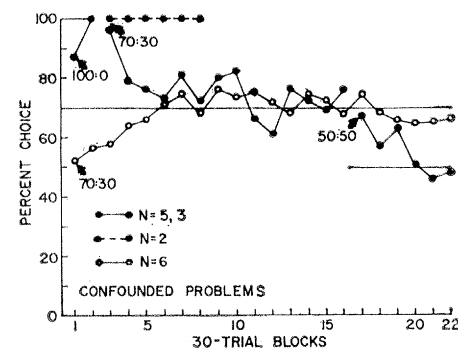


Fig. 2. Performances of 11 painted turtles in 100:0, 70:30, and 50:50 confounded (visual-spatial) problems. *N*, number of turtles in each group; means of groups are plotted.

kind which have shown nonrandomness in matching by mammals failed to give positive results; that is, there was no evidence of reward-following or of any relation at all between choice on any trial and the events of the immediately preceding trial.

Six turtles were trained in spatial problems (both targets the same color, the reward depending on the position of the target). The reward ratio was 70:30 for three of the animals (one position rewarded on a random 70 percent of trials, the alternative position on the remaining trials) and 50:50 for the other three (each position rewarded on a random 50 percent of trials). One of the animals trained on the 70:30 problem maximized, and two of the animals trained on the 50:50 problem developed strong positional preferences. The other three animals showed some tendency to match (the asymptotic choice-ratios were 67:33 and 64:36, respectively, for the two animals trained on the 70:30 problem, and 55:45 for the animal trained on the 50:50 problem), but sequential analysis gave clear evidence of reward-following in each case. The first of the animals trained on the 70:30 problem chose the more frequently rewarded side on 82 percent of trials subsequent to reward on that side, but on only 33 percent of trials subsequent to reward on the opposite side, while the corresponding values for the second animal were 88 percent and 7 percent; the animal trained on the 50:50 problem chose the rewarded side of the previous trial on about 90 percent of all trials.

Eleven turtles were trained on confounded visual-spatial problems (the two targets differing in color, but with the spatial placement of the colors remaining the same from trial to trial). Five animals were begun at 100:0, shifted to 70:30, and later shifted to 50:50. Six other animals were trained throughout at 70:30. In Fig. 2, their performance is plotted in terms of the mean percentage of trials on which the more frequently reinforced alternative was chosen. Of the five turtles trained at 100:0, two continued in 180 trials at 70:30 to show an exclusive preference for the more frequently reinforced alternative; but the preference of the other three shifted rapidly to about 70 percent, and later, when the reward-ratio became 50:50, shifted to about 50 percent. All turtles trained from the outset at 70:30 matched ap-

proximately, their asymptotic preferences for the more-frequently reinforced alternative ranging from 66 to 75 percent. For none of the eight matching animals was there a significant relation between the choices made and the events of immediately preceding trials. Apparently, then, the confounded problem functions as a visual problem for the turtle except where previous 100:0 training has established a strong set for position.

These results for the turtle—random matching in visual problems and maximizing or reward-following in spatial problems—are like those obtained for the pigeon (7) and for adult rats that had been extensively decorticated in infancy (8). They support the inference from the earlier results that random probability-matching is a precortical phenomenon which tends to be suppressed by cortical development, more effectively in the spatial modality than in the visual. It will be in-

teresting to see whether cortical ablation in the turtle produces random matching in spatial problems.

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9. Work supported by ONR contract Nonr 2829(01).

4 March 1965

Visual Perception of Direction for Stimuli Flashed During Voluntary Saccadic Eye Movements

Abstract. *In two different experiments, subjects reported on the visual direction of a flash presented during a voluntary saccade relative to the visual direction of a stimulus viewed prior to the saccade. Under the conditions of the first experiment the report given by the subject was primarily determined by the relative retinal positions of the two stimuli. In the second experiment evidence was obtained for precisely timed shifts in local signs which are due to proprioceptive compensation for changes in ocular position during the saccade.*

As we move our eyes from place to place in a visual field, stationary objects do not normally appear to change their locations, in spite of the changed locations of images of these objects on the retina. It was suggested at least as far back as 1866 that this result is due to a proprioceptive signal regarding the change in eye position which is taken into account in "interpreting" the changed locations of the retinal images (1). However, no clear-cut direct evidence bearing on this position has ever been presented. We have now obtained such evidence by recording eye movements in perceptual situations devised to yield separate measures of the retinal and proprioceptive stimuli. In combination with psychophysical reports these measurements yield information on whether or not (or how much) proprioceptive compensation is involved in the visual

perception of direction. Previously we described experiments in which no evidence was found for the operation of proprioceptive compensation for involuntary eye movements in the judgment of visual direction in the dark (2). In this report we describe two experiments bearing on the existence of proprioceptive compensation during voluntary saccades. The unexpected finding that clear evidence for the operation of such a mechanism was obtained under the conditions of one experiment but not under the conditions of the other opens the entire problem for further detailed parametric investigation.

On each trial of each experiment, the subject, who was in a completely dark room, first viewed a circular 3.5-minute target for 4 seconds with the left eye (the right eye was covered with an eye patch); 300 msec after the