

JOURNAL OF ANIMAL BEHAVIOR

VOL. 6

MAY-JUNE

No. 3

VISUAL PATTERN-DISCRIMINATION IN THE VERTEBRATES—III

EFFECTIVE DIFFERENCES IN WIDTH OF VISIBLE STRIAE FOR THE MONKEY AND THE CHICK

H. M. JOHNSON

Nela Research Laboratory, National Lamp Works of General Electric Company

In an experiment reported some time ago¹ I determined the width of the individual members of a regular system of striae necessary to enable three animals to distinguish the field as striate at a given distance and under the experimental conditions prescribed. The work reported in this paper was done on the same animals, in an attempt to ascertain what difference in width of the members of two regular systems of striae, both of which the animals can distinguish as such, is necessary to effect discrimination between the two systems. The discriminands are two interchangeable circular fields, 6 cm. in diameter and equal in brightness and color. The distribution of energy through the visible spectrum approximated that of a tungsten lamp operated at a specific consumption of 1.25 watts per candle. In the work on the chickens the mean brightness of the fields was 12.24 candles per square meter; in the work on the monkey, 6.67 candles per square meter; and in a supplementary test made on two human subjects, 6.24 candles per square meter. The striae composing the system on the positive field are coarser and fewer in number than those composing the system on the negative field. The animals were fed in the food-compartment

¹ Johnson, H. M. Visual pattern-discrimination in the vertebrates. II. Comparative visual acuity in the dog, the monkey and the chick. This journal, vol 4, 1914, pp. 340-361.

indicated by the positive field, and were punished by an electric shock for attempting to enter the food-compartment indicated by the negative field. In an earlier communication² I described at some length the optical instruments used, and the methods of preparing the stimuli and of training the animals.³ I followed these methods rigidly in the present work except in three particulars. It became necessary, when the differences in width between the members of the two systems of striae became small, to make the adjustments by hand, employing the micrometer screw for the purpose, instead of using the string and pulley mechanism. Further, in this work it is unnecessary that each animal be required to compare the test-fields at the same minimal distance as that prescribed for another animal, in order to make the results comparative. I therefore eliminated the stops in front of the alleys A¹ and A² of the Yerkes box (shown in figure 6 of the last article cited) which I had used in the work on the chicks. This reduced to 50 cm. the minimal distance at which comparison could be made without a choice being registered. The actual distance usually employed by the birds seemed to be between 50 cm. and 60 cm. If the difference in width of the members of the two systems was large as compared with the least effective difference for the individual, the animals tended to choose without comparing except possibly from the position they happened to occupy in the home-compartment when the exit-door was raised and the test-fields exposed. I retained the plate glass partition formerly used in the work on the monkey, in order to limit his movements. In this work he occasionally thrust his head into one opening in this partition and withdrew it without choosing that alley. Such behavior was relatively infrequent, and in such cases I did not exclude the responses. In practically all the presentations in which he compared the two fields before choosing, he inspected them successively with

² Johnson, H. M. Visual pattern-discrimination in the vertebrates. I. Problems and methods. This journal, vol. 4, 1914, pp. 319-339.

³ The original drawing for Figure 1 in that article was lost or destroyed after it had been mailed to the printer. A second drawing had to be prepared hastily and was used. It contains an error which I beg the reader, in the interest of clearness, to correct. The acute angle I, II, in the figure should be lettered ϕ , and the obtuse angle I, II, should be lettered ϕ^1 instead of ϕ . The system of right lines bisecting the obtuse angle should be lettered III. On page 330, in the phrase, "the lines III bisect the angle I, II (ϕ)," the symbol ϕ^1 should be substituted for the symbol ϕ . My responsibility for the error is limited to carelessness in copy and proofreading.

his eyes in or quite near the plane of the windows in the partition—60 cm. from the test-field. In all cases I recorded as the alley "chosen" the one into which the animal first stepped. The animals automatically and instantly registered their choices by breaking the circuit through a signal lamp as they stepped on to the floor of the alley. The third change is the introduction of a shallow copper tray into the Yerkes box, between the exit-door and the alleys A¹ and A². This tray contained a moistened felt pad⁴ on to which the animal had to step before he could enter the alley. This tended to minimize the variability of the resistance of the animal's feet. It is somewhat more satisfactory than the means employed in my earlier work—that of soaking the animal's feet before beginning the daily series of trials.

RELATIVE EASE OF LEARNING FOR INDIVIDUAL ANIMALS

The animals used were a young male Capuchin monkey and two Indian gamecocks. They were described in paper No. 2 of this series, and designated severally as Monkey 2 and Chicks 1 and 2. Since that report was published, Dr. P. W. Cobb refracted the eyes of the birds by skiascopy. The static error

⁴ Breed had used a similar device in his work on the chick. Some such precaution is indispensable to good results if punishment with electric shock is employed. The resistances of dry feet and moist feet are of different orders of magnitude. If an animal is put into the box with dry feet and hands, and if during the series the latter become moist, as from perspiration or contact with urine or wet food, the increased effect of a steady line current may work great disturbance. In my work on audition in dogs I found this factor troublesome. Miss E. M. Smith reports a similar experience. The unsatisfactory results reported by some other experimenters may be partly due to failure to take this precaution. Watson (*Behavior*, p. 60) asserts that some animals "are extremely resistant even to fairly high currents. The rabbit is not disturbed in the smallest degree by a current which is unbearable to the human being." It should be remembered that thick tufts of long hair cover the soles of the rabbit's feet, forming an excellent insulation when dry. When moistened, the water acts as a conductor. The rabbit will then react violently to a current which is not unpleasantly strong when received by the human subject through the moistened finger-tips. I recently demonstrated this fact in a simple experiment on the rabbit. However, even with the best attempts to keep the resistance of the animal's feet constant, the variability is fairly large—as great, I have been told, as 25%. It is impossible to keep the animal's feet free of dirt and grease, which interfere with good contact with the electrodes. It therefore seems unnecessary to use such extreme care to control the steadiness of the line current as some students have done. I have obtained satisfactory results by passing A.C. from the city circuit through the primary coil of a Zimmermann inductorium, connecting a bank of lamps in series with the coil and in parallel with each other. Small changes in intensity of shock can be made by changing the position of the secondary coil with reference to the primary. This method has one advantage over the use of D.C. with an interrupter, in that the noise of the latter, which is often a source of disturbance, is dispensed with.

under mydriasis for Chick 1 was 0.75 D. hyperopia in the right eye and 1.25 D. hyperopia in the left eye. For Chick 2 the error was between 0.25 D. and 0.50 D. hyperopia in both eyes. No astigmatism was discoverable in either bird. After the animals had recovered from mydriasis, Dr. Cobb repeated the tests, but, since the birds were continually changing their accommodation, the results were quite indefinite. In the emmetropic human eye an hyperopia as great as that found for Chick 2 usually exists during mydriasis, owing to lack of tone in the ciliary muscle. It seems fair, therefore, to regard this bird's eyes as practically emmetropic, since no error was discoverable without mydriasis.

Chick 1 failed to establish a perfect or highly accurate habit in 300 trials, although the width of the members of the positive system of striae was three times as great as that of the members of the negative system. At this point I abandoned the attempt to train him. Later on I gave him the problem of discriminating between two regular systems of striae the members of which were equal in width, but differed in direction by 90° . He failed to learn this problem also. When I introduced a 2 to 1 difference in width in addition to the difference in direction, he established a perfect habit in 150 additional trials, and maintained discrimination until the relative width of the members of the two systems was reduced to a 5 to 4 relation. The bird's record over 1100 trials indicated that a difference in either width or direction is ineffective if it is presented alone, but that either difference is effective if it is made sufficiently large and is presented with a maximal difference in the other characteristic. This fact raised some questions of great interest, which I was prevented from studying by an injury to the bird's left eye. I shall, therefore, omit a detailed report on the work done on Chick 1.

Chick 2 and Monkey 2 learned the problem in less than 100 trials each.

BASIS OF DISCRIMINATION

In attempting to train an animal to respond to a difference between two stimuli either of which may be made the variable, it is important to know whether the animal is reacting on the basis of relative difference, or by choosing or rejecting a familiar stimulus. If in work on this problem, the animal can be trained

invariably to compare the test-fields and choose the coarser system regardless of the absolute width of its members, it would seem feasible to adopt the method of right and wrong cases, presenting in haphazard order large and small differences in both directions from the standard, and to treat the results statistically. The advantages of using such a method in preference to the cruder methods on which we have thus far had to rely are obvious.

TABLE 1
DAILY RECORD OF CHICK 2

Date 1914	Width (mm.) of striae on		Number of		Remarks
	Positive field	Negative field	Trials given	Correct responses	
Feb. 13	2 23	0 92	10	8	Not worked on days for which no record is given
" 14	2 23	0 92	10	10	
" 15	2 23	0 92	10	9	
" 16	2 23	0 92	10	9	
" 17	2 23	0 98	10	8	
" 18	2 23	0 98	10	8	
" 19	2 23	0 98	10	9	
" 20	2 23	0 98	10	8	
" 21	2 23	0 98	10	8	
" 22	2 23	0 98	10	9	
" 23	2 23	0 98	10	9	
" 24	2 23	0 98	10	10	
" 25	2 23	0 98	10	10	
" 26	2 23	0 98	10	10	
" 27	2 23	1 00	10	10	
" 28	2.23	1 02	10	8	Disturbed by punishment
Mar. 1	2 23	1 02	10	10	
" 2	2 23	1.08	10	8	Greatly excited by punish- ment Responses very slow Responses very slow More active Active Active
" 3	2 23	1.08	10	10	
" 3	2 23	1 11	10	9	
" 4	2 23	1.11	10	9	
" 5	2 23	1.11	20	15	
" 9	2 23	0.11	10	10	
" 11	2 23	0 11	10	10	
" 12	2 23	0 11	10	10	
" 13	2 23	0.11	10	10	
" 14	2 23	0.11	10	10	
" 15	2.23	0.11	10	10	
" 16	2 23	0 11	5	5	
" 16	2 23	1 04	5	5	
" 16	2 23	1.11	10	10	
" 17	2.23	1 08	5	4	
" 17	2.23	1.11	5	5	
" 17	2 23	1 15	10	10	
" 18	2 23	1 11	5	5	
" 18	2 23	1 15	5	5	
" 18	2.23	1.18	20	18	
" 19	2.23	1 15	5	5	
" 19	2.23	1.18	5	4	

TABLE 1—*Continued*

Date 1914	Width (mm.) of striae on		Number of		Remarks
	Positive field	Negative field	Trials given	Correct responses	
Mar. 19	2 23	1.22	20	16	
" 20	2.23	1.15	5	4	
" 20	2.23	1.22	5	5	
" 20	2.23	1.28	20	11	Taken as threshold
" 20	2 23	0.92	10	10	Given as test of bird's con-
" 21	2 23	1 11	10	10	dition
" 21	4.33	2 23	10	3	{Chose familiar field against
" 22	4 33	2 23	10	4	punishment
" 23	2.23	1.11	10	8	
" 23	4.33	2 23	10	4	{Chose familiar field against
" 24	4 33	2 23	10	2	punishment
" 25	2.23	0.92	10	9	
" 25	1 95	0.92	10	10	
" 25	1.73	0.92	10	8	
" 26	1 95	0 92	5	5	
" 26	1.73	0 92	5	5	
" 26	1.56	0 92	5	5	
" 26	1.42	0 92	10	7	
" 27	1.56	0 92	10	9	
" 27	1.42	0 92	5	5	
" 27	1.30	0 92	10	7	
" 28	1 42	0.92	5	5	
" 28	1.30	0 92	10	5	Taken as threshold
Apr. 5	2 60	0 98	10	9	
" 6	2 60	1 04	10	9	
" 7	2.60	1.04	10	8	
" 7	2 60	1 11	10	9	
" 8	2.60	1 11	5	5	
" 8	2.60	1.20	5	5	
" 8	2.60	1 30	10	9	
" 9	2 60	1.39	5	4	
" 9	2 60	1 44	5	4	
" 9	2 60	1.53	10	10	
" 9	2.60	1 73	10	6	Taken as threshold
" 15	3 12	1 04	10	10	
" 16	3.12	1.04	10	10	
" 17	3.12	1 04	10	10	
" 18	3.12	1.11	5	5	
" 18	3 12	1.20	5	5	
" 18	3 12	1 30	5	5	
" 18	3 12	1.42	5	4	
" 19	3.12	1.42	10	10	
" 20	3.12	1.42	5	5	
" 20	3.12	1 56	10	8	
" 21	3.12	1.56	10	8	
" 30	3 12	1.56	20	15	
May 1	3.12	1.56	10	8	
" 2	3 12	1 56	10	8	
" 3	3 12	1 56	10	9	
" 3	3 12	1.73	10	8	
" 4	3 12	1.30	5	5	
" 4	3.12	1 81	10	7	Taken as threshold
" 5	3.12	1.30	5	5	

TABLE 1—*Continued*

Date 1914	Width (mm.) of striae on		Number of		Remarks
	Positive field	Negative field	Trials given	Correct responses	
May 5	3 12	1 90	10	6	
" 5	3 12	1 04	5	5	
" 5	2 60	1 04	5	5	
" 6	2 23	1 04	5	5	
" 6	1 95	1 04	10	6	Greatly excited by punish- Still excitable [ment]
" 7	2 23	1 04	10	8	
" 11	2 23	1 04	10	9	
" 12	2 23	1 04	10	10	
" 12	1 95	1 04	10	10	
" 12	1 73	1 04	10	8	
" 13	1 73	1 04	5	5	
" 13	1 56	1 04	10	8	
" 13	1 44	1 04	10	6	Taken as threshold
" 13	3 12	1 04	5	5	Taken as test of bird's con- dition
" 14	1 30	0 74	10	10	
" 14	1 20	0 74	20	16	
" 14	1 11	0 74	10	8	
" 15	1 30	0 74	10	10	
" 15	1 04	0 74	10	6	Taken as threshold

TABLE 2
DAILY RECORD OF MONKEY 2

Date 1914	Width (mm.) of striae on		Number of		Remarks
	Positive field	Negative field	Trials given	Correct responses	
June 7	1 561	0 780	10	6	Very inactive
" 8	1 561	0 780	10	4	
" 9	1 561	0 780	10	7	
" 10	1 561	0 780	10	7	Compared in 9 trials
" 11	1 561	0 780	10	8	
" 12	1 561	0 780	10	9	
" 13	1 561	0 780	10	10	
" 14	1 561	0 780	10	10	
" 16	1 561	0 780	10	10	Not worked on days for which no record is given
" 17	1 561	0 822	10	10	
" 18	1 561	0 867	10	10	
" 19	1 561	0 908	10	10	
" 20	1 561	0 976	10	10	
" 21	1 561	1 041	10	10	
" 22	1 561	1 115	10	10	
" 23	1 561	1 201	10	10	
" 24	1 561	1 301	10	10	
" 27	1 561	1 301	10	9	
" 28	1 561	1 301	10	4	
" 29	1 561	1 301	10	7	
" 30	1 561	1 301	10	7	
July 1	1 561	1 301	10	5	
" 1	1 561	0 976	5	5	
" 2	1 561	0 976	5	5	
" 2	1 561	1 115	5	5	

TABLE 2—*Continued*

Date 1914	Width (mm.) of striae on		Number of		Remarks
	Positive field	Negative field	Trials given	Correct responses	
July 2	1.561	1.301	10	8	Taken as threshold
" 3	2.602	1.561	10	6	
" 4	2.602	1.561	10	7	
" 5	2.602	1.561	10	8	
" 6	2.602	1.561	10	10	
" 7	2.602	1.561	10	10	
" 8	2.602	1.561	10	10	
" 9	2.602	1.561	10	10	
" 10	2.439	1.561	10	10	
" 11	2.439	1.561	10	10	
" 12	2.296	1.561	10	10	
" 13	2.296	1.561	10	10	
" 13	2.168	1.561	10	10	
" 14	2.168	1.561	10	9	
" 14	2.001	1.561	10	10	
" 15	1.904	1.561	10	9	
" 16	1.904	1.561	20	19	
" 17	1.904	1.561	10	9	
" 17	1.815	1.561	10	10	
" 18	1.815	1.561	10	10	
" 18	1.734	1.561	10	6	
" 19	1.815	1.561	10	9	
" 20	1.815	1.561	10	9	
" 21	1.774	1.561	10	7	
" 24	1.774	1.561	10	7	
Aug. 10	0.780	0.446	10	6	Taken as threshold In bad condition since July Refused food [24
" 11	0.780	0.446	10	4	
" 12	0.780	0.446	10	9	
" 13	0.780	0.446	10	7	
" 14	0.780	0.446	10	10	
" 15	0.780	0.446	10	10	
" 16	0.780	0.446	10	10	
" 17	0.780	0.520	10	9	
" 18	0.780	0.520	10	9	
" 19	0.780	0.538	10	10	
" 20	0.780	0.558	10	10	
" 21	0.780	0.578	10	8	
" 22	0.780	0.520	3	3	
" 22	0.780	0.578	2	2	
" 22	0.780	0.600	10	10	
" 23	0.780	0.520	2	2	
" 23	0.780	0.558	3	3	
" 23	0.780	0.624	10	10	
" 24	0.780	0.520	2	2	
" 24	0.780	0.558	3	3	
" 24	0.780	0.650	10	10	
" 25	0.780	0.520	2	2	
" 25	0.780	0.558	3	3	
" 25	0.780	0.679	12	7	
" 26	0.780	0.520	1	1	
" 26	0.780	0.558	2	1	
" 26	0.780	0.600	5	5	
" 26	0.780	0.650	3	3	
" 26	0.780	0.655	10	8	

TABLE 2—*Continued*

Date 1914	Width (mm.) of striae on		Number of		Remarks
	Positive field	Negative field	Trials given	Correct responses	
Aug. 27	0 780	0 600	10	9	
" 27	0 780	0 661	10	9	
" 28	0.780	0 600	10	9	
" 28	0 780	0 667	10	10	
" 29	0 780	0 600	10	10	
" 29	0 780	0 673	10	5	Taken as threshold
" 30	1 040	0 780	10	10	
" 31	0 918	0 780	10	10	
Sept. 1	0 918	0 780	10	10	
" 1	0 909	0 780	10	9	
" 2	0 918	0 780	10	10	
" 2	0 897	0 780	10	10	
" 3	0 918	0 780	10	9	
" 3	0 890	0 780	10	7	Taken as threshold
" 4	0 650	0 520	10	10	
" 5	0 624	0 520	10	10	
" 6	0 624	0 520	10	10	
" 6	0 615	0 520	10	8	
" 7	0 624	0 520	10	8	
" 7	0 610	0 520	10	7	Taken as threshold
" 8	0 624	0 520	10	9	
" 8	0 605	0 520	10	7	
" 9	0 520	0 390	10	9	
" 10	0 520	0 400	10	9	
" 11	0 520	0 411	10	10	
" 13	0 520	0 422	10	9	
" 13	0 520	0 434	10	10	
" 15	0 520	0 446	10	9	
" 15	0 520	0 459	10	7	
" 16	0 520	0 446	10	8	
" 16	0 520	0 467	10	8	
" 17	0 520	0 434	10	8	
" 17	0 520	0 473	10	9	
" 18	0 520	0 434	10	10	
" 18	0 520	0 479	10	7	Taken as threshold
" 19	0 520	0 434	10	10	
" 19	0 520	0 488	10	6	
" 20	0 459	0 390	20	17	
" 21	0 459	0 390	10	10	
" 21	0 446	0 390	10	8	
" 22	0 459	0 390	10	10	
" 22	0 441	0 390	10	8	
" 23	0 459	0 390	10	10	
" 23	0 436	0 390	10	9	
" 25	0 459	0 390	9	9	
" 25	0 431	0 390	11	10	
" 27	0 459	0 390	10	10	
" 27	0 427	0 390	10	7	
" 28	0 459	0 390	10	10	
" 28	0 422	0 390	10	10	
" 29	0 459	0 390	10	10	
" 29	0 417	0 390	10	9	
" 30	0 459	0 390	10	10	
" 30	0.413	0.390	12	8	Taken as threshold

TABLE 2—*Continued*

		Width (mm.) of striae on		Number of		Remarks
Date 1914		Positive field	Negative field	Trials given	Correct responses	
Oct.	1	0 459	0 390	10	9	
"	1	0 409	0 390	10	7	
"	2	0 390	0 325	10	10	
"	2	0 390	0 339	10	7	
"	3	0 390	0 339	10	9	
"	4	0 390	0 339	10	10	
"	5	0 390	0 339	10	10	
"	5	0 390	0 347	10	9	
"	6	0 390	0 339	10	10	
"	6	0 390	0 355	10	8	
"	7	0 390	0 339	10	8	
"	7	0 390	0 358	10	10	
"	8	0 390	0 339	10	10	
"	8	0 390	0 361	10	7	
"	9	0 390	0 339	10	10	
"	9	0 390	0 365	10	9	
"	10	0 390	0 339	10	10	
"	10	0 390	0 368	10	10	
"	11	0 390	0 339	10	9	
"	11	0 390	0 371	10	7	
"	12	0 390	0 339	10	9	
"	12	0 390	0 371	10	7	Taken as threshold
"	13	0 347	0 312	20	19	
"	17	0 347	0 312	20	15	Distracted by noise outside
"	19	0 372	0 312	10	8	
"	19	0 347	0 312	10	7	
Nov.	11	0 390	0 312	20	17	
"	12	0 390	0 312	20	15	
"	13	0 390	0 312	20	15	
"	14	0 390	0 312	15	12	
"	15	0 390	0 312	15	15	
"	16	0 434	0 312	20	16	
"	17	0 422	0 312	20	20	
"	18	0 411	0 312	10	10	
"	18	0 400	0 312	10	9	
"	19	0 390	0 312	20	17	
"	20	0 381	0 312	20	20	
"	21	0 372	0 312	10	10	
"	21	0 363	0 312	10	10	
"	22	0 354	0 312	10	10	
"	22	0 346	0 312	10	9	
"	23	0 346	0 312	10	10	
"	23	0 339	0 312	10	8	
"	24	0 346	0 312	10	8	
"	24	0 335	0 312	10	9	
"	25	0 346	0 312	10	9	
"	25	0 332	0 312	10	9	
"	26	0 346	0 312	10	9	
"	26	0 328	0 312	10	9	
"	27	0 346	0 312	10	10	
"	27	0 325	0 312	10	10	
"	28	0 346	0 312	10	8	
"	28	0 321	0 312	10	8	
"	29	0 346	0 312	10	9	

TABLE 2—*Continued*

Date 1914	Width (mm.) of striae on		Number of		Remarks
	Positive field	Negative field	Trials given	Correct responses	
Nov. 29	0 321	0 312	10	5	Taken as threshold
" 30	0 312	0 260	20	16	
Dec. 1	0 312	0 260	10	10	
" 1	0 312	0 264	10	10	
" 2	0 312	0 269	10	10	
" 2	0 312	0 274	10	10	
" 3	0 312	0 279	10	10	
" 3	0 312	0 284	10	10	
" 4	0 312	0 289	10	9	
" 4	0 312	0 294	10	9	
" 5	0 312	0 284	10	9	
" 5	0 312	0 298	10	9	
" 6	0 312	0 284	10	10	
" 6	0 312	0 300	10	8	
" 7	0 312	0 284	10	9	
" 7	0 312	0 304	10	8	Taken as threshold
" 8	0 312	0 284	10	10	
" 8	0 312	0 306	10	5	
" 8	0 312	0 284	10	8	{Control test to determine basis of choice
" 8	0 284	0 260	10	10	
" 9	0 244	0 223	10	9	
" 9	0 240	0 223	10	10	
" 9	0 236	0 223	10	9	
" 10	0 244	0 223	6	6	
" 10	0 234	0 223	10	8	
" 10	0 232	0 223	15	11	
" 11	0 244	0 223	10	9	
" 11	0 232	0 223	10	7	Taken as threshold
" 11	0 223	0 199	10	9	
" 12	0 223	0 199	10	9	
" 13	0 223	0 199	10	9	
" 13	0 223	0 200	10	10	
" 14	0 223	0 200	10	10	
" 14	0 223	0 203	10	10	
" 15	0 223	0 203	10	10	
" 15	0 223	0 208	10	9	
" 16	0 223	0 203	10	9	
" 16	0 223	0 210	13	9	
" 18	0 223	0 203	10	10	
" 18	0 223	0 210	10	8	
" 19	0 223	0 203	10	10	
" 19	0 223	0 210	10	8	Taken as threshold
" 19	0 195	0 173	10	9	
" 20	0 195	0 173	10	9	
" 20	0 192	0 173	10	7	
" 21	0 195	0 173	10	8	
" 21	0 192	0 173	10	9	
" 22	0 200	0 173	10	9	
" 22	0 190	0 173	10	7	
" 23	0 200	0 173	10	9	
" 23	0 190	0 173	15	11	Taken as threshold
1915					
Mar. 4	0 780	0 520	20	19	
" 5	0 780	0 538	10	10	

TABLE 2—*Continued*

Date 1914	Width (mm.) of striae on		Number of		Remarks
	Positive field	Negative field	Trials given	Correct responses	
Mar 5	0 780	0 558	10	10	
" 6	0 780	0 577	10	10	
" 6	0 780	0 600	10	10	
" 8	0 780	0 624	10	9	
" 8	0 780	0 650	10	10	
" 9	0 780	0 678	10	10	
" 9	0 780	0 709	10	9	
" 10	0 780	0 709	10	8	
" 10	0 780	0 723	10	8	
" 11	0 780	0 678	10	8	
" 11	0 780	0 729	10	8	
" 12	0 780	0 678	10	9	
" 12	0 780	0 731	10	10	
" 13	0 780	0 678	10	10	
" 13	0 780	0 743	10	8	
" 14	0 780	0 678	10	10	
" 14	0 780	0 750	10	7	
" 15	0 780	0 678	10	10	
" 15	0 780	0 750	10	7	Taken as threshold
" 16	0 975	0 780	10	9	
" 16	0 918	0 780	10	10	
" 17	0 867	0 780	10	9	
" 17	0 848	0 780	10	9	
" 18	0 867	0 780	10	10	
" 18	0 839	0 780	10	9	
" 19	0 867	0 780	10	9	
" 19	0 830	0 780	10	9	
" 21	0 867	0 780	10	10	
" 21	0 822	0 780	10	9	
" 22	0 867	0 780	10	10	
" 22	0 813	0 780	10	10	
" 23	0 867	0 780	10	9	
" 23	0 805	0 780	10	9	
" 25	0 867	0 780	10	9	
" 25	0 805	0 780	10	9	
" 26	0 867	0 780	10	9	
" 26	0 796	0 780	10	6	
" 27	0 867	0 780	10	9	
" 27	0 796	0 780	10	6	Taken as threshold

If the reader will now examine the daily records of Chick 2 and Monkey 2, shown in tables 1 and 2 respectively, he may observe that the chick was usually disturbed when he was required to avoid a field which he had recently been in the habit of choosing. The records for 21 to 24 March, 1914, exhibit this fact strikingly. Monkey 2 tended to respond in this way in the earlier stages of the work, but later overcame the tendency. On December 8, 1914, I made a control test which tends to make the fact clear. In the week immediately pre-

ceding this test I had required him to choose a field each stripe on which was 0.312 mm wide, and to reject a field each stripe on which was 0.284 mm wide. He chose correctly in 48 out of 50 trials. In this control test I presented the 0.284 mm. system ten times with a system each member of which was 0.312 mm. wide, and ten times with a system each member of which was 0.260 mm wide. The animal was required to choose the coarser system at each trial, thus choosing the 0.284 mm system ten times and rejecting it ten times in the same daily series. The results are shown in table 3.

TABLE 3

Trial	Width (mm) of striae on		Relative position of positive field	Field chosen by the animal	Remarks		
	Positive field	Negative field					
1	0 312	0 284	Right	Right	Compared before choosing		
2	0 312	0 284	Right	Right			
3	0 312	0 284	Left	Left	"	"	"
4	0 284	0 260	Left	Left	"	"	"
5	0 284	0 260	Right	Right	"	"	"
6	0 284	0 260	Right	Right	"	"	"
7	0 312	0 284	Left	Left	"	"	"
8	0 312	0 284	Left	Left	"	"	"
9	0 284	0 260	Right	Right	"	"	"
10	0 284	0 260	Right	Right	"	"	"
11	0 312	0 284	Left	Left	"	"	"
12	0 312	0 284	Right	Right	"	"	"
13	0 312	0 284	Right	Right	"	"	"
14	0 284	0 260	Left	Left	"	"	"
15	0 284	0 260	Left	Left	"	"	"
16	0 284	0 260	Right	Right	"	"	"
17	0 312	0 284	Right	Left	Chose without comparing		
18	0 312	0 284	Right	Left			
19	0 284	0 260	Left	Left	"	"	"
20	0 284	0 260	Left	Left	"	"	"

The animal was punished for choices 17 and 18. He had usually shown a preference for the left-food-compartment. In trials 17, 18, 19, and 20 he inspected the left field only. The field presented on that side at these trials was the field which he had correctly chosen in trials 14, 15 and 16. At trials 1 to 16, inclusive, he inspected both fields before choosing, and in every case he selected the relatively coarser system, regardless of the absolute width of its members. I believe that this animal could have been adapted by training to study by the standard method of right and wrong cases. Chick 2 gave no such promise.

The tendency of Chick 2 to respond by choosing or rejecting the familiar stimulus differs from the behavior of some birds used by Bingham,⁵ which chose the larger of two circles and avoided the smaller without regard to the absolute size of the larger, and without regard to its previous association with reward or punishment. The comparison is worthy of mention as it seemingly points to an individual difference.⁶ Bingham, however, gives no details which indicate how nearly unanimous or how consistent his birds were in manifesting this form of behavior.

AN INCIDENTAL OBSERVATION

One incidental feature of the behavior of Monkey 2 seems deserving of special mention. As was remarked above, I used a plate glass partition across the entrances of Alleys A¹ and A² of the Yerkes box. This partition contained two rather small holes through which the animal had to squeeze himself in order to enter the alley. On two occasions—June 16, 1914, and March 14, 1915, I neglected to insert this partition before giving the first trial of the daily series. On each occasion the animal refused to enter either alley. When I looked into the box to ascertain the cause of his delay in responding I found him groping in large semi-circles with his hands near the plane in which the glass partition belonged, and uttering frequent vocal exclamations. It was necessary to recall him to the home-compartment and insert the partition. It appeared from this behavior that he had become habituated to disregarding the partition as a visual object.

RELATIVE EASE OF DISCRIMINATION

In tables 4 and 5 I have summarized the values taken as "thresholds" for the two animals. The reader may see how these values were obtained by referring to tables 1 and 2, in which the animals' daily records appear. Whenever there

⁵ Bingham, H. C. Size and form perception in *Gallus domesticus*. This journal, vol. 3, 1913, pp. 65 ff.

⁶ Watson (Behavior p. 367) refers to the difference between the behavior of my chick and those of Bingham's as indicating that "this (Bingham's) observation cannot be confirmed." This interpretation is not mine. Had all the birds been worked on the same problem I should not have considered that the behavior of one bird was predictable from the behavior of a few others. But the two problems are so different that there is little basis for comparison.

seemed room for doubt whether the animal's errors were due to the magnitude of the stimulus-difference or to disturbance from some other cause, I presented a larger difference at a number of trials in the same daily series with the smaller difference. If all or most of the incorrect choices were made at the small stimulus-difference, I concluded that discrimination at that stimulus-difference was becoming difficult; if the animals' percentage of correct choices was low for the large stimulus-difference as well, I assumed that the source of disturbance was extraneous.

The values obtained on the two animals are not strictly intercomparable. In work on the monkey I reduced the stimulus-difference by smaller gradations than I could use in the work on the chick, owing to a limitation of the optical instrument by which the field was formed. As the angle of rotation of the gratings over each other becomes very small, as is the case where the width of the visible stripes thus formed is large, a very slight change in the angle of rotation makes a large difference in the width of the visible stripes. In the work on the monkey a larger angle and smaller gradations could be employed, since he was sensitive to much smaller widths than was the chick under similar conditions. I took for "threshold-differences" for the monkey the differences at which his average percentage of correct choices most nearly approximated 75. For the chick I took the stimulus-difference at which the first breakdown of discrimination not apparently due to disturbance from other causes occurred. This procedure is open to criticism in that I did not ascertain to what extent the bird could be made to overcome his uncertainty by continued training. At the time, however, this bird did not react well under punishment. As soon as the stimulus-difference became relatively small he usually refused to inspect both fields and adopted a position-habit. I recognized this defect in the procedure, and in a later piece of work attempted to settle the question.⁷ I found that this bird could be made to improve to a limited extent after very long continued training. The degree of improvement which I was able to elicit is not sufficiently large to invalidate the results herein presented as the rough approximations of the

⁷ Johnson, H. M. Visual pattern-discrimination in the vertebrates IV. Effective differences in direction of visible striae for the monkey and the chick. To appear in this journal.

limits of the bird's discriminative ability which I regard them as being. It will be seen that the threshold-values for the chick vary irregularly from 33% to 42% of the width of the striae on the standard field. The variations may be explained by assuming that discrimination was difficult throughout this region of stimulus-differences. If the bird received punishment several times in close succession shortly after the difference approached this region, he "gave up" earlier, and yielded a larger "threshold" than if his errors were more widely distributed.

Table 5 also shows a great disparity between the "upper" and the "lower" threshold values given by the monkey when the width of the striae on the standard field was 0.520 mm. This fact pointed to a large effect of practice. The magnitudes of the thresholds obtained at the smaller values of the standard stimulus are so much lower than those obtained in the earlier stages of the work at the larger stimulus-values, that it was necessary to make a control test to discover if these differences were not due to the effect of training, instead of being a function of the absolute width of the striae. This test was made between March 4, 1915 and March 27, 1915. It shows quite clearly that the differences were due to the effect of training. The results suggest strongly that if training had been continued sufficiently long after the full effect of practice had been obtained, the values for all the difference-thresholds where the striae on the standard field were over 0.3 mm. wide would have borne a relation to the absolute width of the members of the standard system analogous to Weber's law for brightness. This relation probably does not hold for absolute widths below 0.2 mm., under these experimental conditions, since such fine systems become increasingly hard for the monkey to distinguish as striate. Due to pressure of other work and the small likelihood of Monkey 2 living through many more months, I did not feel justified in carrying this exploratory study farther at the time. Should a similar study ever be made, it would seem advisable to select fewer points at which to determine the animal's threshold, and to give a large number of presentations—several hundred, at least—of a number of differences in either direction from each point. In work on another problem with this animal I found such procedure quite fruitful.

TABLE 4
THRESHOLD CONDITIONS FOR CHICK 2

Width of striae on		Difference per cent width on standard field	Mean of upper and lower thresholds	Remarks
Positive field	Negative field			
*2 23 mm.	1 28 mm.	42		
1 30 "	*0 92 "	41		
*2.60 "	1 73 "	33		
*3.12 "	1.81 "	42		
1 44 "	*1 04 "	38		
1.04 "	*0 74 "	40		

TABLE 5
THRESHOLD CONDITIONS FOR MONKEY 2

1.774 mm.	*1 561 mm.	14		
*1.561 "	1.301 "	17	15 5	
0.890 "	*0 780 "	14		
*0 780 "	0 673 "	14	14	
0 610 "	*0 520 "	17		
*0.520 "	0 479 "	8	11.5	Note training-effect
0.413 "	*0 390 "	5.9		
*0 390 "	0 371 "	4.9	5 4	
0.321 "	*0 312 "	2 9		
*0 312 "	0.304 "	2 6	2.8	
0.232 "	*0 223 "	4		
*0 223 "	0 210 "	5 8	4 9	
0.190 "	*0 173 "	9 8		
0 796 "	*0 780 "	2		
*0.780 "	0 750 "	3 8	2 9	Note training-effect

* Standard stimulus.

COMPARISON WITH HUMAN SUBJECTS

A comparison of the relation between the absolute stimulus-value (expressed in terms of width of striae on the standard field) and the minimal effective differences for the animals with that obtained for human subjects is of some interest. Accordingly I determined this relation for two human subjects by means of the method of limits, using the same visual conditions as for the animals. The magnitudes of the thresholds obtained on the human subjects by the method of limits are not to be compared with those obtained by the discrimination-method on the animals. A threshold-value obtained by the method of limits

is generally smaller than one obtained under the same conditions by the method of right and wrong cases, of which the discrimination-method is a special and rough adaptation. The relation between the absolute value of the standard stimulus and a series of thresholds obtained by either method ought to vary in the same way. This comparison between the two sets of data is the only one which I wish to be made directly, although the values obtained for the monkey and for the human subjects indicate that their sensitivities are of the same order. The two human subjects were Dr. A. G. Worthing (W), a member of the research staff of this laboratory, and Mr. B. E. Shackelford (S), of the University of Chicago, late Brush fellow in this laboratory. Both observers are physicists possessed of a high degree of skill in optical pyrometry—one of the most difficult types of photometric measurements. Perhaps it should be remarked that both observers considered the visual conditions in the present experiment quite trying. An hour or more was usually required for making ten paired readings, which constituted a single sitting. The results are summarized in table 6.

TABLE 6

Width of striae on standard field (mm.)	Upper threshold in mm.	Lower threshold in mm.	Mean threshold per cent standard	Mean variation per cent mean threshold	Mean threshold for the two observers
0.780 { W. S.	0.026 0.019	0.020 0.012	3.0 2.1	58 45	2.6
0.390 { W. S.	0.007 0.014	0.009 0.013	2.1 3.5	28 35	2.8
0.260 { W. S.	0.009 0.006	0.008 0.008	3.3 2.7	40 27	3.0
0.195 { W. S.	0.006 0.009	0.006 0.008	3.1 4.7	49 34	3.9

The relation between absolute width and magnitude of the threshold for the animals and the two human observers is shown graphically in the accompanying figure. The average threshold for the two observers at each stimulus-value was taken merely for convenience in plotting on the scale selected.

SUMMARY

A very large effect of practice was found in the work on the monkey, which indicates the desirability of modifying the discrimination-method for use on the higher mammals.

When the full effect of practice has been obtained, Monkey 2, under optimal conditions, can distinguish differences in width of striae of less than 3%. These values are of the same order of magnitude as those obtained by the method of limits on two human observers possessed of unusual skill in photometry. Chick 2 ceased to discriminate when the difference in width of striae was reduced to a value between 33% and 42%. The relatively poor results of the chick were not due to errors of refraction, as both his eyes were emmetropic.

The discriminative ability shown by the monkey is on the average roughly ten times as great as that shown by Chick 2. His visual acuity, however, is only four to five times as good as that of the same bird. This disparity suggests that difference of width between two systems of visible striae constitutes a more difficult basis of discrimination for the chicken than the mere presence or absence of the striae. The fact that Chick 1 did not learn the problem, although width-difference was effective for him when presented with an ineffective difference in direction, lends support to this belief.

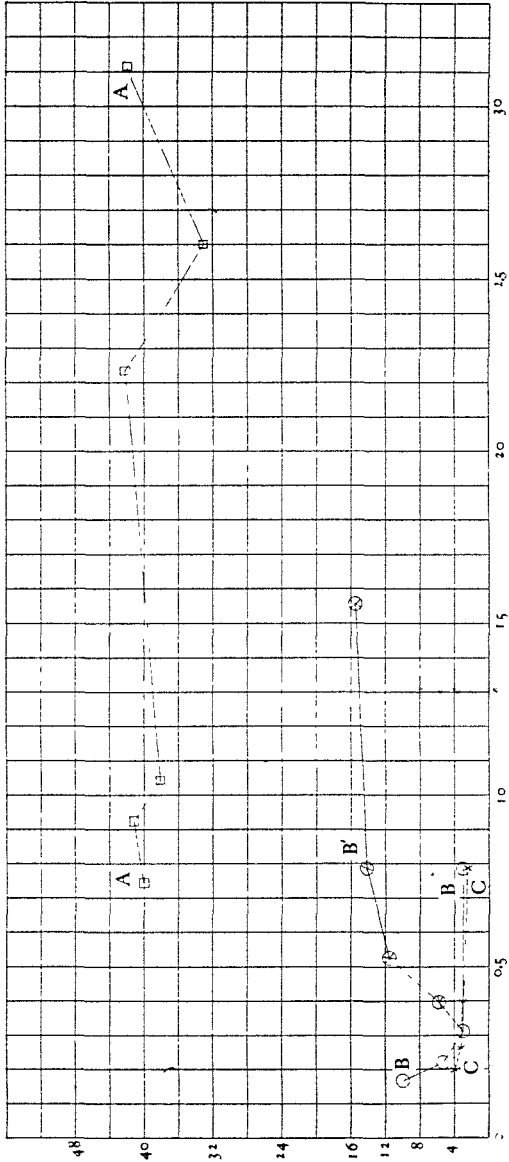
Nothing in the above work indicates that Chick 2 might not have yielded a lower threshold had training been sufficiently prolonged. A later experiment, however, indicates that the chick's susceptibility to improvement under prolonged training is not sufficiently large to affect the order of difference between his results and the monkey's which appears in this work.

For all the subjects, both human and animal, the relation between absolute size of detail and effective difference in size approximates an analog of Weber's law.

For the chick, familiarity was a more effective stimulus-characteristic than relative size of detail, and the bird never overcame the tendency to respond on that basis without continued retraining. The monkey eventually learned to respond on the basis of relative size. His results suggest that he is adaptable to study by a method of much greater precision than the method which was actually employed.

In conclusion I wish to thank Dr. P. W. Cobb for the work of refracting the eyes of the animals, and for making the photometric determinations for me; also, Dr. A. G. Worthing and Mr. B. E. Shackelford for their cheerfulness in undertaking the tedious observations.

Least effective difference per cent standard



Width of striae on standard field (mm.)

Curve A: Threshold values for Chick 2
Curve B': Mean threshold values for Monkey 2, early stages of training
Curve B: Mean threshold values for Monkey 2, later stages of training
Curve C: Mean threshold values for two human observers