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VISUAL SEARCH IN MONKEYS[1]

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Summary.—6 monkeys were trained to search a visual display for a target stimulus. Their search time increased linearly with the number of irrelevant stimuli (N) and at 60 msec./item was comparable to the performance of man on similar tasks. Error scores were not linearly related to N, nor did they change in a systematic way as N increased.

Visual search has been widely investigated in man and is of considerable theoretical importance (see, e.g., Neisser, 1967), but apart from a preliminary experiment mentioned by Lashley (1948), it has never been studied in subhuman primates. Monkeys have advantages over man as experimental animals, particularly if we wish to determine the brain mechanisms underlying visual search. We must begin by analyzing their capacities for visual search. The experiment described here measured the performance of monkeys searching for a single target stimulus among a varying number of irrelevant stimuli.

METHOD

Subjects

Six monkeys were used, 5 immature male rhesus (*Macaca mulatta*), approximately 1 to 2 yr. old when training started, and an immature female baboon (*Papio cynocephalus*), 2 to 3 yr. old. They were partially food-deprived while the experiment was being run, being given 150 gm. of Modified Laboratory Animal Diet 41B (Oxo Ltd.) daily. During training for the visual search task outlined below a detection threshold for the target stimulus was determined (Latto & Iversen, in preparation). Apart from this, all *S*s were experimentally naive.

Apparatus

A fully automatic testing chamber was specially designed and built for this experiment. The monkey had free access to the manipulanda shown in Fig. 1. Pressing the 2-in. long observing response bar (A) caused the stimulus display to be back projected onto the two 'pearlite' stimulus-response panels (B). (The projector shutter was fully open after 10 to 15 msec.) The stimuli remained on for 5 sec. or until the monkey had pressed one of the panels. If the panel containing the target stimulus was pressed, a 190-mgm. banana flavored food pellet (CIBA pharmaceutical) was delivered to the food-cup (C) beside it, and the small light (D) over the food-cup was switched on for 3 sec. If the other

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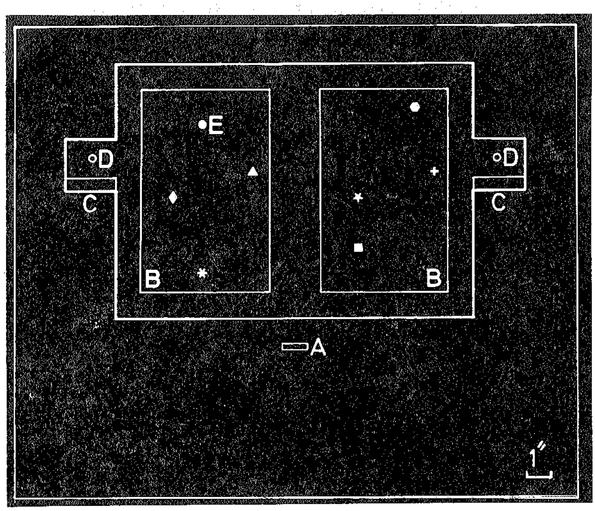

FIG. 1. The manipulanda and an example of the stimulus displays used

panel was pressed or if no response was made, there was a 5-sec. period of darkness in the testing chamber. Both the darkness and the food-cup lights signalled a period of time-out, when pressing the observing response bar had no effect. Apart from these constraints the task was entirely self-paced. The inside of the testing chamber was painted matte black, except for a frame round the stimulus-response panels, the observing response bar, the food-cups and a one-way vision screen in the wall opposite the manipulanda. White noise was played through a loudspeaker above the chamber.

The stimuli had a luminance of 100 ft-L against a background of 0.32 ft-L. The target stimulus (E) was a 0.3-in. circular disc and it occurred with equal probability in any one of a matrix of 40 positions covering the two panels, with the constraint that it must occur twice in each position in every 80 trials. Irrelevant stimuli (1, 3, 5, 7, or 9) could occur in any of the other 39 positions, with the constraint that there must be equal numbers of stimuli, including the target, on each panel. The irrelevant stimuli were drawn at random from the seven geometrical shapes shown in Fig. 1. (The different stimuli occurred with the same over-all frequencies, but there was no constraint for individual trials so that displays commonly contained two or more of the same stimulus.) The stimulus display was projected with a Kodak Carousel S-AV projector which held 81 slides at a single loading. Since testing was done in blocks of 100 trials, 19 stimulus displays were repeated in each session.

The response accuracy and latency (the interval between pressing the orienting response bar and the stimulus-response panel) were recorded. All data collecting and programming equipment was outside the room containing the testing chamber.

Procedure

Training.—The monkeys were trained initially with the target stimulus alone. When they had performed for three successive days above 90% correct (300 trials per day) and with less than 1 min. variation in their total latency sum for each session, they were given 300 trials on the condition with one irrelevant stimulus. If they scored 90% or better, they were moved on to three irrelevant stimuli for the next day's testing. This continued until they reached the final condition of nine irrelevant stimuli.

Testing.—There were six stimulus conditions, with 0, 1, 3, 5, 7, or 9 irrelevant stimuli. Error scores and latencies of correct responses were collected from 600 trials in each condition, in blocks of 100 trials. So each monkey performed 3,600 trials at 3 × 100 trials/day. The blocks of trials occurred in random order with the one important constraint that each condition should be followed by every condition once.

Results

All monkeys performed above 90% correct on all six stimulus conditions. Fig. 2 shows the group mean for each condition. Table 1 gives a summary of the statistical analysis. (The data from the condition with no irrelevant stimuli were excluded from the statistical analysis of both per cent correct and latencies because it could be argued that this condition was perceptually different from the others. But this did not alter any of the levels of significance.) There was no systematic decrease in accuracy as the number of irrelevant stimuli increased

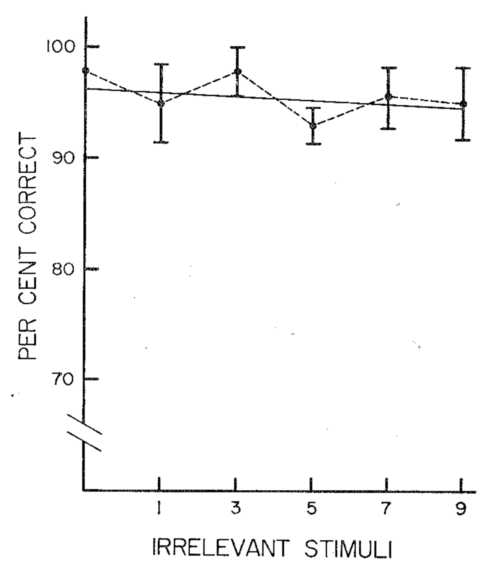

FIG. 2. Mean per cent correct for all monkeys on each stimulus condition. (The continuous line is the regression line for all points excluding the condition with no irrelevant stimulus.)

TABLE 1
ANALYSIS OF VARIANCE: RESPONSE ACCURACY

Source	*df*	*MS*	*F*	*p*
Between stimulus conditions	4	17.25	11.28	<.001
Linear regression	1	0.42	0.27	
Deviation from linearity	3	22.86	14.95	<.001
Between subjects	5	22.61	14.80	<.001
Rhesus	4	17.06	11.15	<.001
Rhesus vs baboon	1	44.83	29.30	<.001
Remainder	20	1.53		

although, as Table 1 shows, there was a significant variation over the different conditions.

Fig. 3 shows the mean latencies for correct responses in the different stimulus conditions. There was a clear increase in latency as the number of irrelevant stimuli increased. The statistical analysis summarized in Table 2 showed that this regression did not deviate significantly from linearity. The regression line

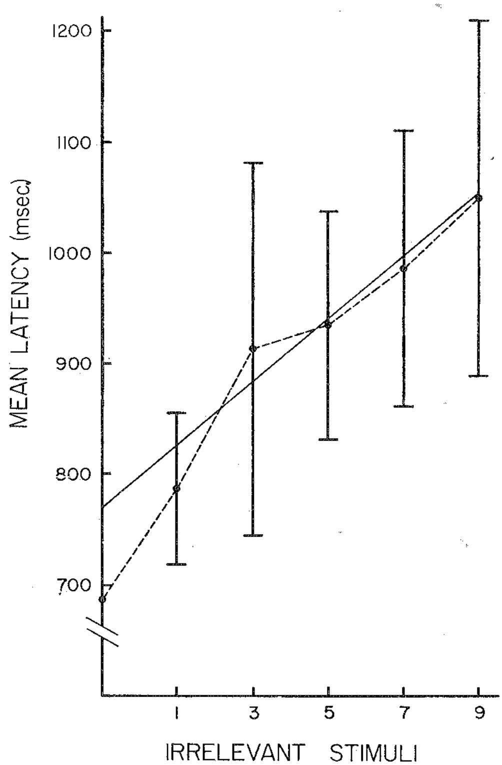

FIG. 3. Mean response latency for all monkeys on each stimulus condition. (The continuous line is the regression line for all points excluding the condition with no irrelevant stimulus.)

TABLE 2
ANALYSIS OF VARIANCE: RESPONSE LATENCY

Source	*df*	*MS*	*F*	*p*
Between stimulus conditions	4	51,896.9	13.80	<.001
Linear regression	1	196,081.7	52.06	<.001
Deviation from linearity	3	3,835.3	1.02	
Between subjects	5	84,683.3	22.49	<.001
Rhesus	4	50,366.0	13.37	<.001
Rhesus vs baboon	1	221,952.7	58.93	<.001
Remainder	20	3,766.7		

shown in Fig. 3 has the equation: $L = 30.1\ N + 783.1$; L = latency in msec., N = number of irrelevant stimuli. That is, there was a latency increase of 30.1 msec. for every additional irrelevant stimulus. Or, since on average only half the stimuli will be viewed on each trial before the target is found, the visual search time was approximately 60 msec./item.

DISCUSSION

All six monkeys were successfully taught to search for a target stimulus in an array of irrelevant stimuli. The most striking feature of their performance is the linearity of the relationship between the latency (L) and the number of irrelevant stimuli (N). Without exception, experiments on visual search in man have obtained the same result (Gregg, 1954; Green & Anderson, 1956; Neisser, 1963; Neisser, Novick, & Lazar, 1963; Oostlander & de Swart, 1966; Solley & Snyder, 1958; Smith, 1962; Thomas & Solley, 1963). The values of the performance parameters are obviously dependent on such factors as stimulus-response compatability, the nature of the response and the area of the stimulus display. For example, in man, visual search time varies from 20 msec./item (Neisser, 1963) to 3,000 msec./item (Solley & Snyder, 1958). So there is little point in comparing values unless these conditions are reasonably well matched. The response parameters in Gregg (1954) are closest to those used here and he found a mean latency with a single stimulus of 670 msec., compared with 780 msec. for the best fit line or 680 msec. for the experimental mean found here with monkeys. Similarly, stimulus parameters are closest in Green and Anderson (1956) where the search time is 130 msec./item, and Smith (1962) where the search time is 340 msec./item, compared with a search time found here of 60 msec./item. It seems reasonable therefore to conclude that monkeys perform a visual search at very similar speeds to man. Any slight tendency to be faster than man could be partly because the monkeys were far more highly practiced than the human *S*s in any of the experiments mentioned, and partly because they were making more errors than humans in comparable experiments.

Error scores, unlike latencies, did not show a positive linear relationship with N. All animals showed an increase in errors from 0 to 1 irrelevant stimulus, that is, when a form discrimination was introduced, but there was no systematic change as N increased from 1 to 9. Experiments with man are divergent on this point. Archer (1954) found that error scores were independent of all parameters except practice, whereas Gregg (1954) says, though he gives no data, that errors showed the same pattern as reaction times. It is possible that the monkeys showed a positive interaction of errors with N early on in training, and that with practice this disappeared, although my data do not suggest this. Given that monkeys show a finite error rate on a discrimination task, it is likely that increasing the number of discriminations to be made will increase the number of errors. It seems possible, therefore, that for these highly trained monkeys visual search did not involve a series of discrete discriminations.

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