ically cannot be excluded, although the small dose administered, the low outflow perfusion pressure, and the high binding coefficient of cholera toxin would make such a result unlikely (*10*).

There was no change in the concentrations of sodium, potassium, or chloride in CSF after cholera toxin administration in unperfused and perfused animals. This absence of change in fluid composition has been noted in intestinal fluid and endolymph when their secretion was stimulated by cholera toxin (*3, 5*).

Rudman (*11*) has suggested that cyclic AMP plays a role in the pathogenesis of increased intracranial pressure associated with brain trauma. Except for questionable stimulation of CSF production with ouabain and spironolactone (*12*), cholera toxin appears to be the most potent activator known to increase the brain's fluid production. Although there is considerable flexibility in the amount of fluid that can be passively handled by the arachnoid villi, the restrictions imposed by the Monro-Kellie doctrine (a rigid skull with a constant total CSF, brain, and blood volume) call for a biochemical mechanism for fluid production control. Our data implicate cyclic AMP as a mediator of brain ventricular fluid production control.

MEL H. EPSTEIN
Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, Maryland 21205
ARTHUR M. FELDMAN
SAUL W. BRUSILOW
Department of Pediatrics, Johns Hopkins University School of Medicine

References and Notes

1. G. A. Robison, R. W. Butcher, F. W. Sutherland, *Cyclic AMP* (Academic Press, New York, 1971).
2. M. Field, D. Fromm, Q. Al-Awqati, and W. B. Greenough, III, *J. Clin. Invest.* **51**, 796 (1972).
3. C. C. J. Carpenter and W. B. Greenough, III, *ibid.* **47**, 2600 (1968).
4. R. M. Friedler, K. Kurokowa, J. W. Coburn, S. H. Massry, *Kidney Int.* **7**, 77 (1975).
5. A. M. Feldman and S. W. Brusilow, *Proc. Natl. Acad. Sci. U.S.A.* **73**, 1761 (1976).
6. H. Davson, *Physiology of the Cerebrospinal Fluid* (Churchill, London, 1970).
7. J. R. Pappenheimer, S. R. Heisey, E. F. Jordan, J. Downer, *Am. J. Physiol.* **203**, 763 (1962).
8. $F = r \times [(C_{out} - C_{in})/C_{out}]$ where F = production, r = perfusion rate, C_{out} = concentration of isotope out, and C_{in} = concentration of isotope in.
9. R. E. Curran, M. B. Mosher, E. S. Owens, J. D. Fenstermacher, *Exp. Neurol.* **29**, 546 (1970).
10. K. Kurokawa, R. M. Friedler, S. G. Massry, *Kidney Int.* **7**, 137 (1975).
11. D. Rudman, A. Fleischer, M. H. Kutner, *N. Engl. J. Med.* **295**, 635 (1976).
12. H. Davson and M. B. Segal, *J. Physiol. (London)* **209**, 131 (1970); F. R. Domer, *Exp. Neurol.* **24**, 54 (1969); W. W. Oppelt and R. F. Palmer, *J. Pharmacol. Exp. Ther.* **154**, 581 (1966).
13. We thank T. Smith for laboratory supervision and assistance. This work was partially aided by grants from the National Foundation–March of Dimes, grants NS11274, NIH5 TO1 HD00091-10, and AM07145 from the National Institutes of Health, and by the Kerr Foundation.

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Visual Search in the Pigeon: Hunt and Peck Method

Abstract. *Pigeons pecked at small forms displayed on an oscilloscope screen under computer control. The birds were required to find a small o amid varying numbers of x forms. A photocell glued to the bird's beak provided a signal to the computer when the beak approached a form, and the computer recorded the time and target of the response. As in some similar studies with human subjects, errors and reaction times increased with number of x forms displayed. The method appears promising for further studies of search and of other processes related to perception and information-processing in birds.*

Rapid, accurate search of the visual environment is necessary to the survival of many species; search also appears to be one of the more informative varieties of the pattern recognition problem. The pigeon seems an appropriate subject with which to extend and generalize search findings from experiments with humans (*1*). Some aspects of form identification have been studied in pigeons, and something is known of their basic visual functions (*2, 3*); also important, for the present method, is their strong tendency to peck at visual targets that signal presentation of food (*4*).

This report summarizes a method for studying search in pigeons and presents data on the effect of visual noise on the speed of search. The pigeon subject searched for a small o displayed under computer control on an oscilloscope screen set in the wall of an experimental chamber (Fig. 1). The o was often accompanied by a number of x's of the same size as the o (4-mm diameter). Although all the forms seemed to be continuously present during search, they actually appeared in rapid sequence about 150 times per second (*5*). A small photocell, glued to the bird's beak, sent signals via a connecting wire and amplifier to the computer whenever the beak approached one of the forms. When the input signal exceeded a set threshold, the computer recorded the type and location of the form being displayed at that instant; this information specified the time and target of the peck response.

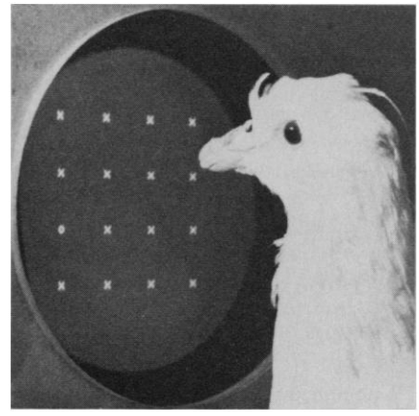
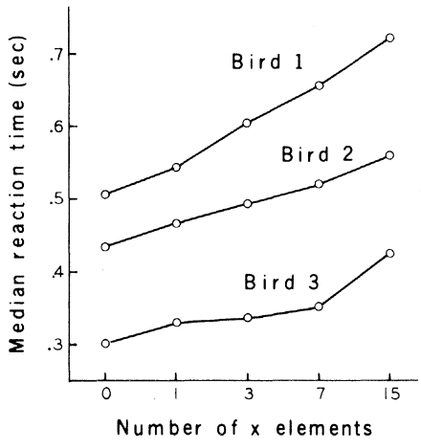


Fig. 1. One of the search displays and a pigeon with a photocell (visible as a lump on the beak). During experimentation, the only illumination came from the display.

Three food-deprived White Carneaux pigeons were trained by standard methods to eat from a grain feeder located below the display screen, and to peck at the target o when it appeared on the screen. For several hundred presentations, one or more x forms appeared along with the o, and presentation of food followed only pecks at the o; the birds quickly learned to peck only at the o. The final search procedure was then introduced. On each trial, the o first appeared alone in the center of the screen; this served to position the bird for the subsequent display. When pecked, the o vanished and 0.2 second later the search display appeared. This display comprised one o (the target) and either 0, 1, 3, 7, or 15 x (noise) forms. Each form was located at one of the 16 positions defined by 4 × 4 matrix 7 cm square, subtending a visual angle of approximately 50 deg. The search display continued until the bird pecked at one of the forms. Then a rectangular blanking stimulus appeared briefly in each position and, unless reinforcement occurred, the next trial was initiated 0.5 second later. If the bird pecked the o in the search display, food was presented with a probability of .083, and the next trial started 0.5 second after the end of food presentation. If the bird pecked an x, no food appeared, and the same display was repeated on the next trial. Except for such correction trials, the o was located randomly within the matrix, with the restriction that within 80-trial blocks it appeared in each location just five times, once under each of the five noise conditions. The x elements had random positions with respect to the 15 remaining matrix locations. Each bird received at least 25,000 trials with this procedure, in daily sessions of 800 or 880 trials (*6*).

The data from six 880-trial sessions were pooled for each bird, with the omission of responses on error and correction trials and on the first 80 trials of each session. Reaction time, defined as time from search display onset until the peck response, was determined for all birds and



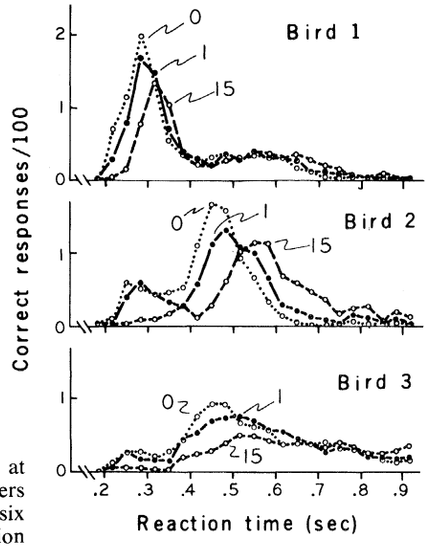


Fig. 2 (left). Median reaction times of pecks at the o when accompanied by varying numbers of x forms. Data are from 4800 trials in six sessions. Fig. 3 (right). Three of the reaction time distributions for each bird. The clearest effects of increasing the number of x stimuli appear to be a decrease in the number of responses in the first mode and a shift of the second mode to longer times.

conditions. Median reaction time was lowest when the o appeared alone, and increased with increasing number of noise elements (Fig. 2). Error rates (not shown) also were perfectly correlated with number of noise elements, rising from less than 1 percent for one x to maxima (for 15 x's) of 8.8 percent for bird 1, 5 percent for bird 2, and 2.6 percent for bird 3. The reaction time shift is seen in the distributions in Fig. 3; for clarity, only the 0, 1, and 15 x conditions appear. The distributions are all bimodal, with responses of bird 1 concentrated in the first mode and those of the other birds in the second mode. It is possible to interpret much, if not all, of the change in first-mode responses as a dropping out of the fastest responses with increasing numbers of noise stimuli, but the second mode clearly shifts in time, as best seen in the data for bird 2.

The data have several significant aspects. The pigeon search times were elevated by visual noise in much the same manner as those of humans required to search among relatively confusable or numerous items. This suggests that the birds did not process all parts of the display independently and in parallel; constant reaction times across conditions would have suggested such parallel processing. Nonetheless, the pigeons' search did proceed with relatively high speed and accuracy over a display with a very large visual angle and without notable head scanning movements (pigeon eye-movements are quite small). This finding may be related to the pigeon's complex retina, which might be specialized for acuity over a broad area.

It is tempting to associate the two modes of the reaction time distributions with a sequence of processes, such as a rapid "primary detection response" followed, if the primary process fails, by a longer-latency "secondary response" (*7*). Such an interpretation is made more complex by the finding that multimodal reaction time distributions appear to characterize pigeon peck responses in many situations, even, as Heinemann reported, those that involve no decision-making (*8*). The present data, however, are unusual in showing a clear shift in the timing of at least the second peak in the reaction time distribution; such shifts have rarely if ever been reported. Additional work with the method outlined here could provide the raw material for a model of search processes in the pigeon, as well as aiding in the identification of those aspects of search that are general across species. Such behavorial information may eventually also guide physiological studies of search and other information-processing functions.

DONALD S. BLOUGH
Department of Psychology,
Brown University,
Providence, Rhode Island 02912

References and Notes

1. Many methods have been used to study human visual search; representative papers that present theory and data for two somewhat different lines of experimentation are by W. H. Teichner and M. J. Krebs [*Psychol. Bull.* **8**, 15 (1974)] and G. Wolford [*Psychol. Rev.* **82**, 184 (1975)].
2. For example, D. Blough, *J. Opt. Soc. Am.* **47**, 827 (1957); P. M. Blough, *Percept. Psychophys.* **12**, 342 (1972); W. Hodos, *et al.*, *J. Exp. Anal. Behav.* **25**, 129 (1976); A. A. Wright, *Vision Res.* **12**, 1447 (1972).
3. J. Hendricks, *J. Exp. Anal. Behav.* **9**, 501 (1966).
4. E. Hearst and H. M. Jenkins, *Sign Tracking* (Psychonomic Society, New York, 1974).
5. A small on-line computer, the LINC, displayed the forms on a Tektronix type 503 oscilloscope with P2 phosphor. The forms were composed of dots in a 4 by 4 matrix. The o consisted of eight dots, two on each edge of the matrix; the x also consisted of eight dots, one in each corner and four in the center of the matrix. At an apparent luminance of about 2 cd/m², the intermittency should have been well above the pigeon's critical flicker frequency (*3*). A full description of the technique is in preparation.
6. Bird 1 received most of its training in sessions with single noise conditions; that is, only one of the various numbers of x stimuli appeared on every trial for an entire session. Possibly this training variation bears some relation to the relatively fast responding of this bird.
7. This has been suggested for human search [for example, W. K. Estes, *Percept. Psychophys.* **12**, 278 (1972)].
8. E. G. Heinemann, *Bull. Psychonom. Soc.* **3** (**1B**), 75 (1974).
9. Supported in part by PHS grant MH-02456.

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GM_2 Ganglioside Lysosomal Storage Disease in Cats with β-Hexosaminidase Deficiency

Abstract. *Two kittens with progressive neurologic disease had increased concentrations of GM_2 ganglioside in their cerebral cortex. Examination under the light microscope revealed cytoplasmic vacuolation of neurons and hepatocytes. Transmission and scanning electron microscopy demonstrated cytoplasmic inclusions encompassed by membranes in various central nervous system cell types and in hepatocytes. Beta-*D-N-*acetyl-hexosaminidase activity was reduced to about 1.0 percent of normal in brain, liver, and cultured skin fibroblasts of the diseased kittens; both major electrophoretic forms, A and B, of the enzyme were deficient. In fibroblasts from the parents of the diseased kittens, this enzyme activity was intermediate between that of affected and normal cats, suggesting an autosomal recessive mode of inheritance of the enzyme defect. Histopathological and ultrastructural lesions, glycolipid storage, enzyme defect, and pattern of inheritance are similar to those of human GM_2 gangliosidosis type 2.*

Ganglioside storage diseases resulting from inherited defects in lysosomal hydrolases cause devastating neurologic disorders and have been observed in man (*1*), cats, dogs, cattle, and swine (*2*). Neuronal accumulation of GM_2 ganglioside resulting from deficient activity of one or more isozymes of β-D-*N*-acetyl-hexosaminidase (E.C. 3.2.1.52) is the most common ganglioside storage dis-