**AN INFRARED SYSTEM FOR THE DETECTION OF A PIGEON'S
PECKS AT ALPHANUMERIC CHARACTERS ON A TV SCREEN:
THE DEPENDENCY OF LETTER DETECTION ON THE
PREDICTABILITY OF ONE LETTER BY ANOTHER**

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Three pigeons pecked at letters of the alphabet and at the symbol "?" displayed on a computer-driven cathode ray screen. A 4 by 4 matrix of infrared emitting and detecting diodes and associated circuitry identified the location of a pigeon's responses to the screen. Responses at the target letter *T* were probabilistically reinforced with food whenever *T* appeared in a string of three letters in the middle of the screen. Responses at the symbol "?" appearing below this string were probabilistically reinforced whenever *T* did not appear. The letter *F* anywhere in the three-character string either strongly predicted the occurrence of the target letter *T*, in two conditions, or predicted its nonoccurrence, in a third. This manipulation of the frequency with which the familiar letter *F* predicted *T* was shown to change the function relating probability of a correct peck at the symbol "?" to the number of *F*s in the string. This effect may be interpreted as an instance of the phenomenon where an organism's acquired knowledge changes what it sees.

Key words: computer display, visual search, perception, animal cognition, pecks, pigeons

Discriminative stimuli in experiments with animal subjects have become increasingly complex, featuring various kinds of spatial arrays (e.g., Schwartz, 1980), naturalistic images (Herrnstein & de Villiers, 1980; Kamil, 1984; Sands & Wright, 1982), alphanumeric displays (Blough, 1977, 1982), and other extensive sets of stimuli. Experiments such as these suggest that in the future, it may no longer be correct to note that "behaviorists have never been very much interested in perception" (Killeen, in press).

Computer graphics offer one solution to various technical problems that arise when complex stimuli are presented (Taylor, Klitzke, & Massaro, 1978). But this solution to problems of stimulus presentation only defines new problems in recording of responses when infrahuman subjects are used.

Techniques of recording responses to a cathode ray tube (CRT) have included photocells mounted on a pigeon's beak (Blough, 1977), pressure-sensitive materials, and multiple transparent keys fitted over the CRT (Blough, 1982).

The present paper describes a solution to the problem of recording responses directed at relatively small, individual features generated on a CRT display by a digital computer. As an illustration of the effectiveness of the apparatus, it is used here with animals in what can be interpreted as a demonstration of an effect with an important history in the philosophy of science and with an important role in contemporary research in human perception: that what one has learned affects what one sees (Hanson, 1969; Wittgenstein, 1953).

METHOD

Subjects

Three experimentally naive White Carneaux pigeons were maintained at 80% of their free-feeding weights.

This research was supported in part by a grant from the Biomedical Research Support Grant to the University of Utah. The authors wish to thank David Bodily and Jana Salazar for their help in conducting the experiment. Reprint requests may be sent to Charles P. Shimp, Department of Psychology, University of Utah, Salt Lake City, Utah 84112.

Apparatus

The apparatus may be conveniently described in terms of three different parts: the computer, the experimental chamber, and the infrared circuitry for detecting pecks at a CRT.

Computer. The TERA 8510/A microcomputer is based on a DEC LSI 11 and has, for its generation and price, a flexible and powerful graphics capability (Post & Fox, 1982). However, many of the personal computers in today's marketplace provide similar or superior ease in programming graphics and at substantially reduced costs.

Experimental chamber. The chamber was constructed of plywood and duplicated the internal dimensions of standard commercial chambers such as those manufactured by Lehigh Valley Electronics. It differed from those mainly in the response panel, which contained the usual access to a food hopper, but instead of the usual pecking key there was an opening 18 cm by 13½ cm behind which was mounted a 9-in Sanyo television monitor. Around the edges of the monitor screen were mounted four copper-clad printed circuit board (PCB) strips soldered together to form a rectangle. Infrared (IR) emitter and detector mounts (see below) were 5 mm (inside diameter) brass tubes soldered to this frame. There were four such tubes on each of the four sides of the rectangular frame, providing a 4 by 4 matrix of vertical and horizontal beams that together could detect 16 locations in front of the screen. Each such location was an intersection of a particular one of the four horizontal IR beams and a particular one of the four vertical beams. The 4 by 4 matrix was centered across the middle of the screen, with the top and bottom row of the four equidistant rows 27 cm and 24½ cm, respectively, from the floor of the chamber. The horizontal distance from the left-most column to the right-most column was 3½ cm.

Circuit description. The operational amplifier (op amp) configuration in Figure 1 performs signal comparing and conditioning tasks. Whenever the voltage at the positive input of the op amp falls below the voltage at the negative input of the op amp, the op amp output falls from a high to a low level. This con-

figuration also converts the small voltage change generated by the phototransistor into a bilevel signal (0 and 5 volts) that a computer can use directly.

When no peck is detected, phototransistor Q1 is illuminated by the IR beam emitted by IR light-emitting diode (LED) P1. Under these conditions Q1 is turned on and a high level is supplied to the positive input (Point A) of op amp IC1. Resistor R3 is adjusted so that the voltage at IC1's negative input (Point B) is slightly lower than the voltage at Point A. This gives a high level at IC1's output (Point C). When a peck occurs, Q1 no longer is illuminated and turns off. Point A is now effectively grounded through resistor R2. Point B is at a higher potential than Point A, giving a low level at Point C.

Construction. Construction of the electronic circuit is straightforward and may be accomplished by mounting the components (with the exception of P1 and Q1) on a perforated board and wiring them together, or a PCB may be designed and used. All resistors except R3 are ¼ watt 5% tolerance. R3 is a 10-turn trim potentiometer. IC1 is one fourth of a RCA SK 3643 quad op amp (Radio Shack #276-1711 may be substituted). P1 is a Texas Instruments TIL 31. Substitutes should not be used because the TIL 31 emits a beam angle of only 10 degrees. All substitutes we have tried emitted a much wider beam and therefore were unsatisfactory. Q1 is a Texas Instruments TIL 81 which is manufactured to be spectrally compatible with the TIL 31.

Construction of the mounting frame is only slightly more complicated. Four strips of copper-clad PCB material were soldered together to form the mounting frame. No dimensions for the frame are given since it must be sized to fit a particular computer monitor's display screen. One brass tube (inside diameter of 5 mm) for each IR LED and phototransistor were then soldered to the frame at appropriate locations. It is suggested that target points first be displayed on the monitor and that measurements then be taken from the outside of the CRT to each target point in both the horizontal and verti-

Fig. 1. A circuit for detecting pigeons' pecks by means of interruption of infrared beams. One circuit is required for each infrared beam in the system. For example, a 4 by 4 matrix requires 8 circuits.

cal planes, to ensure exact placement of the brass tubes. Each target point must fall exactly behind the intersection of two IR beams. Since the TIL 31 emits a beam that diverges by only 10 degrees, each LED tube must be aligned exactly with its corresponding phototransistor tube. This was accomplished by slipping a tube over a 5-mm diameter rod, soldering the tube to the frame, and removing the rod. Note that the LED tubes must be electrically isolated from the phototransistor tubes. Once the frame is complete, the TIL 31s and TIL 81s can be slipped into the outside ends of the cases that will not allow them to be inserted too far. The only purpose of the brass tubes is to provide a convenient means of alignment and mounting of the TIL 81s and TIL 31s. Their length is not critical. The frame may be attached to the monitor by any convenient means, with care taken to ensure that the center portion of the CRT, which curves outward, does not interrupt the beams.

Adjustment. With the IR beams unobstructed, adjust R3 until the LED indicator comes on, and then reverse the adjustment only until the indicator goes out. After all the circuits are adjusted, simulate a peck with a

pencil while watching the indicators to make sure only the proper one lights up. Periodic readjustment may be needed due to temperature drift of the components.

Operation. The circuit in Figure 1 is set up as a zero-level detector. By using a wheatstone bridge configuration consisting of Q_1 , R_1 , R_2 as the input, a zero voltage can be obtained by balancing the bridge through adjustment of R_2 . When balancing the bridge, the infrared emitter P_1 must be on and must be detected by the phototransistor Q_1 . When a balanced condition is reached, the operational amplifier IC1 will change states and the output will be +5 volts, causing the output LED (D_2) to go out. When the beam is broken, the bridge is unbalanced, causing the inputs to the operational amplifier to be at different potentials; this causes the output to change states, from +5 volts to 0 volts, and to turn on the LED (D_1). This signal can then be interfaced to a computer for data collection.

Reliability, cost, and miscellaneous comments. The apparatus has been in use for roughly 3 hr a day for well over a year, during which time only two problems have arisen. First, the inexpensive Sanyo monitor tends to drift

when warming up, causing a horizontal shift in the displayed characters. A simple solution to this problem is to leave the monitor on all the time or, preferably, to use a high-quality computer monitor instead of an inexpensive television monitor. Second, the sensitivity of two or three of the IR detectors gradually drifts and has several times required adjustment of the corresponding variable resistors shown in Figure 1. Otherwise, the reliability of the system has been exemplary. The cost of the entire IR system is very low—roughly \$70.00—and all parts are readily available.

For some purposes a larger or smaller matrix might be required and could easily be arranged by adding or deleting rows or columns of emitters and detectors and associated circuitry. Spaces between rows or columns could be increased, although with a mounting frame having the dimensions described here, they could not be much decreased. The beam angle of the diodes, the distance between adjacent diodes, and the distance emitters and detectors interact in a sufficiently complex manner that some trial and error is probably necessary to determine optimal frame size and best placement of diodes on the frame for a particular installation.

Procedure

Each discrete trial began with the onset of a houselight and display on the CRT of four characters. Three letters appeared behind the top IR beam and defined the symbol string. The fourth symbol, ?, appeared 15 mm beneath the middle letter. If the target letter *T* appeared anywhere in the symbol string, a peck directly at it broke the corresponding combination of vertical and horizontal infrared beams, signaled to the computer that a correct peck had occurred, and a reinforcer (1.5-s access to mixed grain) was delivered with probability .5. The end of reinforcement started a 5-s intertrial interval. If *T* did not appear in the symbol string, a peck at ? was reinforced with probability .33. A peck at any character in the symbol string when *T*

was not present, or at ? when *T* was present, blanked the screen, turned off the houselight, and started a 2-s correction interval. When this 2-s interval timed out, the same stimuli appeared as before, and continued to do so until a correction response ended the trial. Correction responses at *T*, but not at ?, were reinforced with food. Correction responses at ? simply ended the trial.

The target letter *T* appeared on a random half of the trials, so that half the time the correct response was at a letter (*T*) in the symbol string and half the time it was at the ?. The appearance of a second letter, *F*, was related to the appearance of *T* in a way that was experimentally manipulated. In Condition 1 and its replication, Condition 3, the letter *F* appeared on most of the trials on which *T* also appeared. In Condition 2 the letter *F* never appeared when *T* appeared. Thus, in Conditions 1 and 3, *F* strongly predicted the appearance elsewhere in the symbol string of the letter *T*, whereas in Condition 2, *F* predicted the absence of *T*.

The exact manner in which the preceding was accomplished was as follows. For each trial, the computer first determined with probability .5 whether the familiar letter *F* would appear. The letter *F*, because it appeared on half the trials, was much more frequent than any other letter except the target and therefore occasionally is called the "familiar" nontarget. If *F* did occur, then the computer picked *T* with probability .9 (0 in Condition 2), and if *F* did not occur, it picked *T* with probability .1 (1 in Condition 2). The computer then randomly picked additional letters from the alphabet to produce a three-letter symbol string. This procedure was arranged so that whenever *T* appeared, it appeared only once. The letters selected were randomly assigned to the left, middle, and right positions on the screen. As a result, *T* could appear in any of three positions.

Perhaps a few examples will help to illustrate these arrangements. A bird might confront *TBF*, or *FTF*, or *CAT*, in which case a peck at *T* would be reinforced with probability .5. Or, it might confront *BFZ*, *XAA*, or *FFF*, in which case a peck at ? would be

reinforced with probability .33. In each case, a peck at any incorrect character recycled the correction procedure.

Pretraining was elaborate because both the procedure and apparatus were novel. In general, pretraining consisted of numerous variations in the intertrial interval and in the probabilities of reinforcement for correct pecks at *T* and ?. Pretraining lasted roughly 10 months. There were approximately 300 to 550 trials per 1-hr session. Conditions 1, 2, and 3 lasted approximately 45, 26, and 34 days, respectively. These condition durations depended partly on direct observation of the subjects, partly on stability of the number of trials completed per day, and partly on comparisons with other literature according to which discriminations should have at least partially developed in the time allotted here to each condition. As in some other work on letter identification in pigeons (Blough, 1982), we make no claims that behavior was asymptotic. In any case, the statistical analyses were performed only later.

RESULTS

The results take the form of a number of statistics. These were computed in the following ways. The overall relative frequency of a correct response, $P(C)$, equals the number of responses at the letter *T* when it appeared in the symbol string, plus the number of responses at the symbol ? when *T* did not appear, all divided by the total number of responses. In the computation of this and all

subsequent statistics, only the initial choice response on a trial was included: Any subsequent errors and the final correction response within a trial were excluded because these presumably were at least partially controlled by the correction contingency, not simply by the stimuli on the CRT. The relative frequency of a correct target detection given a response to the symbol string, $P(T/S)$ equals the number of responses at the letter *T* divided by the total number of responses at symbols in the string. The relative frequency of pecking some symbol in the string (not necessarily the target), $P(S/T)$, given that the target was present, equals the number of responses at a character in the string divided by the total number of responses when *T* was present. The relative frequency of a correct response at the symbol ?, $P(?/T)$, equals the number of responses at ? when the target was absent divided by the total number of responses when *T* was absent. Finally, the relative frequency of a correct response at ? given that the target was absent and there were *n* familiar symbols (i.e., *n* instances of the letter *F*, with *n* = 0, 1, 2, or 3), $P(?/T \text{ and } n \text{ F})$, equals the number of responses at ? when *T* was absent and there were exactly 0, 1, 2, or 3 *F*s, respectively.

Table 1 shows these statistics for each bird in each condition. Each value in Table 1 is an average over the last 3 days of a condition. Preliminary to noting the chief effect of the experimental manipulation, there are a few other points to observe. The overall probability of a correct response $P(C)$ was

Table 1

The probability of a correct response to a symbol, either *T* or ?, in the context of different letter strings.

	Condition 1				Condition 3 (replication of #1)				Condition 2			
	Bird 1	Bird 2	Bird 3	Average	Bird 1	Bird 2	Bird 3	Average	Bird 1	Bird 2	Bird 3	Average
$P(C)$	.72	.88	.57	.72	.74	.77	.52	.68	.54	.77	.33	.55
$P(T/S)$	.70	.86	.55	.70	.72	.93	.49	.71	.52	.94	.38	.61
$P(?/T)$	.85	.95	.82	.87	.85	.95	.96	.92	.62	.91	.50	.68
$P(?/T \text{ and } 0 \text{ F})$	.86	.94	.84	.88	.82	.95	.96	.91	.67	.58	.33	.53
$P(?/T \text{ and } 1 \text{ F})$	.72	.88	.83	.81	.72	1.00	1.00	.91	.59	.92	.47	.66
$P(?/T \text{ and } 2 \text{ F})$	.63	.89	.58	.70	.70	.97	.67	.78	.63	.90	.47	.67
$P(?/T \text{ and } 3 \text{ F})$	.72	.97	.50	.73	.71	.94	1.00	.88	.62	.91	.56	.70
$P(S/T)$	.82	.94	.53	.76	.88	.64	.06	.53	.86	.67	.49	.67

Fig. 2. The probability of correctly reporting that the target letter *T* was not in the symbol string (i.e., the probability of correctly pecking the symbol ? as a function of the number of instances of the familiar letter *F* in the string).

far above chance in all cases except for Bird 3 in Condition 3, when this bird had an extreme bias in favor of pecking ? instead of a symbol in the string. This is reflected in Table 1 by a very low value of $P(S/T)$ for Bird 3 in Condition 3.

The chief effect in the data is the change in correctly reporting the absence of the target as a function of the experimental manipulation, according to which the letter *F* in the string either predicted the likely presence of the target letter *T* (Conditions 1 and 3) or its absence (Condition 2). Although the relation is not always monotonic, and is much more apparent for Bird 1 than for Bird 2, the probability of correctly reporting no target tends to decrease as the number of *F*s increases (in Conditions 1 and 3) and to increase in Condition 2. This relation, averaged over subjects, appears in Figure 2. Average performance was always higher in Condition 3 than in Condition 1: In each case, the higher of the two filled circles in Figure 2 is for Condition 3. The only serious anomaly in the figure, that for Condition 3 for trials with three *F*s, is attributable exclusively to one bird (Bird 3), the behavior of which, as already described above, was otherwise anomalous in Condition 3.

In summary, the results show that a pi-

geon's correct detection of no target letter depended on the degree to which another letter predicted the target's presence or absence. When the familiar letter usually predicted the target, this familiar nontarget's appearance made a pigeon more likely to respond incorrectly as if the target were present (i.e., to peck a symbol in the string), and this effect became larger as the number of familiar nontargets increased. That is, a pigeon less often correctly pecked ? (to request the next string) when the number of familiar characters increased. When the familiar letter predicted the target's absence, a pigeon more often detected no target; again, this effect was larger with greater numbers of familiar nontargets.

DISCUSSION

The apparatus used here may permit the more convenient investigation of a wide range of issues in stimulus control. This apparatus generally facilitates the study of any problem in which the structure of a complex stimulus is systematically varied and in which it is also important to have a bird respond directly at specific features of the stimulus. Computer-driven CRTs gave a flexibility in generating and displaying images that importantly changed research on human perception, but that methodological innovation has remained fairly difficult to implement with nonverbal animal subjects. It is to be hoped that the present inexpensive infrared system for detecting responses will promote methodological flexibility with any subject that can essentially point at specific features on a television screen.

The utility of this apparatus was demonstrated here by showing how it makes an important problem accessible to laboratory research on animal cognition. The general problem is how acquired knowledge changes how one sees (Hanson, 1969; Wittgenstein, 1953). A dependency of seeing on knowing may preclude what sometimes in the philosophy of science is called a "neutral observation language." If this is so—if acquired knowledge importantly affects how one

sees—then a scientist's training may affect his seeing in a manner that makes objective observation impossible or even conceptually meaningless (Hanson, 1969). In short, the problem investigated here is an important one, and to study it with nonverbal animals, indeed even birds, may bring a new perspective to its basic nature, which nearly always has been discussed purely in terms of linguistic knowledge.

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Received February 23, 1984

Final acceptance December 12, 1984

APPENDIX

The parts necessary for construction of the apparatus are given below. With the exception of IC1 (see Note 2), the parts specified are sufficient to construct one circuit.

Resistors

- R1-2.7 K ohms
- R2-220 K ohms
- R3-1 mega ohm 10 or 20-turn trimpot
- R4-1.5 K ohms

Semiconductors

- P1-Texas Instruments TIL 31 infrared light-emitting diode (Note 1)
- Q1-Texas Instruments TIL 81 infrared phototransistor (Note 1)
- IC1-RCA SK 3643 quad op amp (Radio Shack #276-1711) (Note 2)
- D1-Red light-emitting diode

Miscellaneous

- Perforated board or printed circuit board, hook-up wire, enclosure for circuits, blank copper-clad board strips for frame, 5 mm (inside diameter) rod, mounting hardware

Note 1: Do not substitute these parts (see text).

Note 2: Only $\frac{1}{4}$ of this IC is used per circuit. If more than one circuit is to be built, one IC will be required for every four circuits.