AUTOSHAPING AS A PSYCHOPHYSICAL PARADIGM: ABSOLUTE VISUAL SENSITIVITY IN THE PIGEON

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A classical conditioning procedure (autoshaping) was used to determine absolute visual threshold in the pigeon. This method provides the basis for a standardized visual psychophysical paradigm.

Key words: autoshaping, vision, psychophysics, pigeons

Animal psychophysics relates physical variables to sensory function by means of a behavioral analysis. To provide valid information, responding must vary with the presence and absence of stimulus change in a reliable fashion. Current animal psychophysical methods rely heavily on stimulus control procedures from operant conditioning. While there are strong advantages to operant methods over earlier reflexive methods (Stebbins, 1970), they are not without difficulties (Blough, 1958, 1972). A recent development in classical conditioning offers a procedure which can be adapted for use as a visual psychophysical technique.

In 1968, Brown and Jenkins described "autoshaping", a classical conditioning procedure which controls directed motor action. They found that pigeons would reliably approach and contact a stimulus from which they had learned to predict imminent food delivery. In their experiments a response key was illuminated prior to the magazine delivery of grain. Thereafter, food-deprived pigeons reliably pecked the response key during these periods of illumination even though no response-reinforcer contingency had been programmed.

The present note describes the use of this classical conditioning procedure to determine absolute visual sensitivity in the pigeon. The technique was found to be fast, reliable, and easily instrumented.

METHOD

Subjects

Three experimentally naive White Carneau and one experimentally naive homing pigeon, 10 to 19 months old, were reduced to 75 to 80% of their free-feeding body weights for the duration of the study.

Apparatus

The experimental chamber measured 50.8 by 36.8 by 33.3 cm. The interior was painted flat black. A stimulus patch 8 mm in diameter was projected via a fiber optic bundle to the rear center of a translucent response key located at eye level. Mixed grain was presented with a standard food magazine. The magazine was dimly illuminated with a red General Electric incandescent lamp Model 327, 28 VAC. Irradiance measured at the entrance to the magazine was approximately $20\mu\text{W}/\text{cm}^2$. An acrylic barrier, also painted flat black, was placed in the chamber effectively reducing it to about one half its original volume in order to keep the bird in physical proximity to the response key. The light source, a Tungsten halogen lamp with a color temperature of 3250°K , was mounted in a Kodak Carousel projector. The original carousel lens was replaced with a simple aluminum barrel constructed to hold filters. A double convex lens 33 mm in diameter with a focal length of 90 mm was located within the barrel and imaged light on a fiber optic bundle fixed to the end of the barrel. The other end of this fiber bundle was mounted 5 mm behind the response key. A flag type shutter was adjusted to cross the beam path in a slot in the barrel. The intensity of the light (unattenuated by filters) incident on the irra-

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diance probe of a Tektronix Model J16 digital photometer placed 32 mm in front of the key (the approximate location of the bird's eyes) was approximately $320 \mu\text{W}/\text{cm}^2$. The projector had been modified to accommodate switching from electromechanical programming circuitry housed in an adjacent room. Kodak Wratten neutral density (ND) gelatin filters (nominal values: .3, .6, .9, 1.2, 1.5) were mounted in 50.8 by 50.8-mm slide frames for use in the projector. The effective densities of the filters were measured at the key with a Tektronix Model J16 digital photometer. White noise was present in the chamber throughout the study at an approximate level of 72 db A scale SPL re .0002 dynes/cm².

Procedure

Initially, three daily 30-min habituation sessions were conducted during which the houselight and magazine light were constantly illuminated. Magazine training commenced on Day 4 and proceeded to a criterion of eating readily from the magazine on each of 10 to 15 consecutive magazine presentations.

The pigeons were then exposed to a training phase. Across the initial training sessions, the houselight was completely faded out and the magazine light gradually reduced to a low level. Subjects dark adapted for about 15 min prior to each session. Three types of events were programmed: key illumination for 8 sec (CS); food presentation for 8 sec (US); key illumination followed immediately by food (CS-US)¹. During each 70-min session, these events

occurred 32, 12, and 16 times respectively. CS, US, and CS-US events were randomized with respect to each other and occurred aperiodically at intervals averaging 60 sec. Four different random arrangements of these events were used, never the same one during two consecutive sessions. The rationale for this training procedure was to engender autoshaped responding while approximating the CS-US pairings, and the lack of pairing that would occur, from the bird's point of view, during threshold determination when the CS would occasionally be of subthreshold intensity. It was therefore important to present some US's alone during training so that eventually during testing, subthreshold presentations of CS's paired with US's would not represent a radical departure from prior experience. This is important from a psychophysical standpoint because changes in procedure or perceived changes in procedure between training and testing conditions may occasion changes in behavior unrelated to the sensory variable of interest. The subject may be spuriously controlled by cues other than or in addition to target cues thereby giving a false psychophysical function. Or competing behavior may develop which totally destroy stimulus control of sensory reporting, i.e., the animal engages in other types of behavior. CS's were occasionally given alone to enhance asymptotic rates of responding. Acquisition, as measured by numbers of required reinforcers, is not adversely affected by a partial schedule. Yet final rate of responding is enhanced (Gibbon, Farrell, Locurto, Duncan, & Terrace, 1980; Terrace, Note 1). This was done to condition the strongest level of responding so as to better weather the stress of threshold conditions, a typically fragile time in most animal psychophysical experiments.

After a pigeon reached the criterion of pecking on 90 to 100% of the CS's within a session, the average intensity of the CS's was reduced

¹A slight variation of the CS-US procedure which involved overlapping the CS with US by 2 sec was later introduced during testing. The CS in this case was presented for 10 sec. Eight sec after CS onset the US was presented for 8 sec as previously described. However, responding during the CS was measured only during the first 8 sec to make data collection comparable to the originally described procedure. Responses occurring during the 2 sec of CS-US overlap were discarded. A return to the original CS-US non-overlapping procedure was later instituted. About one-half of the achromatic thresholds were determined using the CS-US overlapping procedure.

The CS-US overlap procedure was introduced to reduce the probability of food presentation being paired with responding on a darkened key since subjects typically continued to respond for a fraction of a second after the CS was terminated (CS "spillover" responding) especially near threshold. Coincident with this responding was the availability of food when a US was programmed to follow a CS. The overlapping procedure was designed to eliminate this spurious relationship and

thereby enhance stimulus control (see Woodruff & Williams, 1976). The mean achromatic threshold under the overlapping procedure was $-6.61 \log \mu\text{W}/\text{cm}^2$. The mean achromatic threshold under the non-overlapping procedure was $-6.15 \log \mu\text{W}/\text{cm}^2$. The difference of .41 log units was in large part contributed by an atypical threshold from one subject under the overlapping procedure. Observations of daily response patterns indicated that the "overlapping" procedure did not appreciably enhance stimulus control, so the original procedure was reinstituted.

across sessions. This was accomplished by incrementing the density of filters in front of the projector before the session. Thus, the differences in intensity among CS's within a session remained the same but the average intensity of all the CS's was reduced across sessions. One to three sessions were typically given before the average intensity of the CS's was further reduced. The test phase began when the pigeon failed to respond on 10 to 20% of the CS presentations. An average of 34 sessions was required from the first day of adaptation to the beginning of the test phase.

During test sessions the US was no longer presented alone. Forty CS alone and 20 CS-US presentations were given per session. Average CS intensity was further reduced as described above. This resulted in a descending series of intensities across sessions and a mixed presentation of stimulus values within any given session.

Following this, an ascending series of stimulus intensities was given until the pigeon again contacted the key on 90 to 100% of the CS presentations.

Threshold was defined as that stimulus intensity at which the pigeon pecked the response key on 50% of the CS's (trials). A threshold determination was based on the average of a descending and ascending series. Two or three determinations of threshold were made for each subject.

In a second part of the experiment, using the same subjects, thresholds for two monochromatic wavelengths, 506 nm and 546 nm, were determined. Test procedures were identical to those described above. Threshold at both wavelengths was measured for each White Carneaux.

RESULTS AND DISCUSSION

All threshold attempts for the three White Carneaux are presented in Figure 1. The left panel shows functions generated during ascending stimulus conditions; the right panel shows analogous functions generated during descending stimulus conditions. The thresholds for the homing pigeon are presented in Figure 2.

Mean log intensities ($\mu\text{W}/\text{cm}^2$) of the stimulus at absolute threshold for the three White Carneaux, Subjects 1018, 1616, 3550, were -6.15 , -6.29 , -6.57 respectively. The thresh-

old for the homing pigeon, Subject 2, was -5.43 . The mean estimate of absolute scotopic threshold expressed as illuminance was $3.47 \log \mu\mu\text{L}$. This is somewhat lower than the $4.4 \log \mu\mu\text{L}$ reported by Blough (1956).

Thresholds ($\log \mu\text{W}/\text{cm}^2$) for the White Carneaux at wavelength 506 nm were: -7.41 , -7.26 , -7.46 . Thresholds at wavelength 546 nm were: -7.32 , -7.02 , -7.31 . Relative sensitivity to these two wavelengths as reflected by differences in absolute threshold averaged $.16 \log$ units. This is in approximate agreement with both behavioral and electrophysiological data. The expected difference based on the Dartnall nomogram (Dartnall, 1953) with a λ max of 502 nm is $.26 \log$ units. The electroretinographic work of Ikeda (1965) and Graf and Norren (1974) indicated a difference in sensitivity to these two wavelengths of from approximately $.24$ to $.26 \log$ units. Blough's (1957, 1958) behavioral measures of scotopic spectral sensitivity indicated a difference in sensitivity of approximately $.26 \log$ units.

In general, approximately 20% of trials with a response in this study can be attributable to a "background" or "basal" level of responding apparently *not* under visual stimulus control. This is reflected in the failure of the psychophysical functions in Figures 1 and 2 to reach the zero percent-of-trials-with-a-response point. However, stimulus control was more than adequate to allow an operational definition of threshold as that point at which 50% of the stimulus presentations occasioned a response. In addition, intertrial interval responding did not change as a function of stimulus intensity.

Pearson product-moment coefficients of correlation between trials with a response and several other dependent measures are shown for all subjects and conditions in Table 1.

Columns designate variables to which percent trials with a response have been related. Rows designate instances of threshold determination and are labeled as to wavelength. It can be seen that the correlation between percent trials with a response and mean latency to the first response, mean number of responses per CS, and mean number of responses per CS excluding CS's in which no responding occurred, was high. Percent trials with a response did not correlate strongly with responding during the interevent intervals. (The interevent interval response measure included responses occurring at times other than during a CS, a US, a CS-US

Fig. 1. Percent trials with a response as a function of stimulus intensity for all replications for all three White Carneaux pigeons. The left panel shows functions generated during ascending stimulus conditions; the right panel shows analogous functions generated during descending stimulus conditions. Top, middle, and lower segments present psychometric functions resulting from using achromatic, 546 nm and 506 nm wavelengths respectively. Each data point is based on 60-180 CS stimulus presentations (trials) across 1 to 3 daily sessions. Stimulus intensity 32 nm in front of the response key at log I = 0 equals $320 \mu\text{W}/\text{cm}^2$.

Fig. 2. Percent trials with a response as a function of stimulus intensity for the homing pigeon, achromatic condition.

Table 1

Correlations between percent trials with a response and other dependent measures as a function of subject and stimulus condition.

Subject and stimulus condition	Dependent measures				df
	Latency to first response	Number of responses per CS	Number of responses per CS*	Number of responses per interevent interval	
1018					
Achromatic	-.99*	.85*	.69*	.06	14
506 nm	-.98*	.80*	.34	-.40	15
Achromatic	-.98*	.96*	.71	.65	8
546 nm	-.99*	.89*	.77*	.30	11
1616					
Achromatic	-.98*	.76*	.76*	.03	22
506 nm	-.94*	.86*	.63*	-.02	17
546 nm	-.93*	.87*	.87*	-.41	8
Achromatic	-.95*	.91*	.90*	-.39	8
3550					
Achromatic	-.99*	.88*	.82*	.28	22
Achromatic	-.99*	.97*	.92*	-.15	16
506 nm	-.99*	.97*	.95*	.18	7
546 nm	-.98*	.99*	.98*	-.34	5
Achromatic	-.96*	.95*	.95*	-.09	7
2					
Achromatic	-.98*	.98*	.73	-.93*	4
Achromatic	-.99*	.94*	.86*	.41	7

Note. Stimulus conditions and their replications are listed in the order in which they were given for each subject.

*Number of responses per CS excluding CS's in which no responding occurred.

*Statistically significantly different from 0 at $\alpha = .01$.

or during the first 8 sec following a CS alone event. Responses occurring during the first 8 sec following a CS alone were discarded as "spill over" responses.) That is, knowledge of the number of trials on which a response occurred was not predictive of level of interevent interval responding. Interevent interval responding did not tend to increase as detection became more difficult.

In general, the above classical conditioning procedure (i) was easily instrumented, (ii) required no initial hand shaping, or remedial training, and (iii) established reliable stimulus control in a visual detection task. Additionally it may have application to other species. Similar control over approach and contact behavior has been demonstrated in a variety of species (Hearst & Jenkins, 1974). With appropriate adjustment of time parameters and selection of US, autoshaping may provide the basis for a standardized visual psychophysical paradigm for other species.

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