PIGEONS' PREFERENCES FOR STIMULUS INFORMATION: EFFECTS OF AMOUNT OF INFORMATION¹

LEONARD GREEN AND HOWARD RACHLIN

WASHINGTON UNIVERSITY AND SUNY AT STONY BROOK

A concurrent-chain procedure was used to study pigeons' preferences as a function of amount of information. Pigeons chose between two terminal links. Both terminal links ended in food reinforcement with probability (p) and in blackout with probability ($1 - p$). One terminal link (noninformative link) was signalled by a stimulus uncorrelated with either food or blackout. The other terminal link (informative link) was signalled by stimuli correlated with these outcomes. Amount of information conveyed by these stimuli was varied across conditions by changing the probability of reinforcement (p) and blackout ($1 - p$). The pigeons strongly preferred the informative link, and preferences were greater at p values above 0.50 than for their complements. The pigeons engaged in different behaviors during the stimulus periods, suggesting that the value of informative stimuli may be in their function as discriminative stimuli for interim activities and terminal responses.

Key words: information, uncertainty reduction, choice, concurrent chains, interim activities, terminal responses, key peck, pigeons

Factors other than the simple pairing of stimuli and responses with reinforcement affect the way that the stimuli influence behavior (*cf.* Bloomfield, 1972; Segal, 1972). One such factor is thought to be the information value of an arbitrary stimulus, which reports about reinforcement conditions but does not by itself affect those conditions. The information an event conveys to an organism can be specified in terms of the degree to which it reduces uncertainty (Garner, 1962). Organisms prefer situations whose onsets reduce uncertainty about consequent reinforcement conditions to situations in which such uncertainty remains high, even though both situations ultimately lead to the same reinforcement conditions (Bower, McLean, and Meacham, 1966; Prokasy, 1956). The present experiment sought to determine the extent to which these preferences can be altered by changes in the amount of information or changes in the amount by which uncertainty is reduced.

The average uncertainty as to which of two mutually exclusive events will occur on a given

trial can be specified (Shannon and Weaver, 1949) according to the equation:

$$H = p \log_2 \frac{1}{p} + (1 - p) \log_2 \frac{1}{(1 - p)} \quad (1),$$

where H refers to the amount of uncertainty or information expressed in bits, and p and $(1 - p)$ are the probabilities of occurrence of the two events. If the two events are equally probable, then the uncertainty as to which event will occur is maximal, and, therefore, the information provided by the occurrence of that event is maximal at 1.0 bits. To the degree that the two events are not equiprobable, uncertainty is necessarily less. For example, if one event occurs on 80% of the trials and the other event on 20% of the trials, information is now 0.72 bits. If experimental subjects are generally sensitive to amount of information or uncertainty, then preferences for informative situations might be expected to decrease as H is decreased.

However, in experiments that have examined values of H other than 1.0 and 0.0, preferences have not varied systematically with the values tested. Bower *et al.* (1966) presented their pigeons with a choice between an informative key that, when pecked, provided signals as to which of two fixed-interval schedules was in effect and a noninformative key that,

¹This research was supported by an NIMH Fellowship and an NSF Grant. The authors are grateful to Xenia Coulter for her comments on the manuscript. Reprints may be obtained from Leonard Green, Department of Psychology, Washington University, St. Louis, Missouri 63130.

when pecked, produced signals uncorrelated with the schedules. When the two fixed intervals occurred with equal probability, the average percentage choices for the informative key was 93%. When the probability of the larger of the two fixed intervals was increased to 0.80, thus reducing the amount of information provided by the informative key, average percentage choices remained at 93%. Similarly, Hendry (1969, Experiment B5) allowed his pigeons to choose between a mixed schedule, in which red and green keylights were uncorrelated with the two different fixed-ratio schedules, and a multiple schedule in which the red key signalled the FR 10 and the green key signalled the FR 90. Preferences for the multiple schedule were very strong, but did not vary as a function of the probability of the FR 10.

Eckerman (1973) varied uncertainty through a considerable range of values by manipulating the relative frequencies of occurrence of two different fixed-interval schedules. In this case, preferences did change as the relative frequency of the smaller FI varied; however, the average preference function obtained did not follow from Equation 1. Whereas Equation 1 predicts symmetrical preferences around 0.50, assuming the reinforcing effect of a stimulus is monotonically related to the amount of information provided by that stimulus, Eckerman found that preferences were greater for the range of frequencies from 0.03 to 0.50 than for the range from 0.50 to 0.97.

Other studies have also reported deviations from the expected preference function derived from Equation 1, in particular that positive and negative information are not equal in value (Dinsmoor, Flint, Smith, and Viemeister, 1969; Dinsmoor, Browne, and Lawrence, 1972; Jenkins and Boakes, 1973; Mulvaney, Dinsmoor, Jwaideh, and Hughes, 1974). In other words, it does not appear "that 'bad news' (is) just as much 'news' as 'good news'" (Bloomfield, 1972).

Wilton and Clements (1971) modified the preference-for-information hypothesis by assuming that only the positive stimulus has reinforcing value and not, as Equation 1 predicts, both positive and negative stimuli. In this case information, H , would be defined as:

$$H = p \log_2 \frac{1}{p} \quad (2),$$

where p is the probability of the positive stim-

ulus. As a result, amount of information is not symmetrical around the 0.50 p value, but in accord with certain preference studies is highest at a p value of 0.37. Hendry (1965), for example, allowed a chimpanzee to make observing responses that converted a mixed schedule to a multiple schedule, in which a 30-sec period of variable-ratio 100 (VR 100) reinforcement alternated irregularly with a 30-sec extinction period. The number of observing responses was greatest when the probability of the VR 100 period was approximately 0.35. Observing responses decreased as the probability varied above and below that value. Similarly, Wilton and Clements (1971) found higher observing response rates by pigeons when $p = 0.20$ than when $p = 0.80$, and McMillan (1974) found that pigeons in changing from mixed VI EXT schedules to corresponding multiple schedules varied their observing responses as predicted by Equation 2.

However, results inconsistent with Equation 2 have also been reported. Whereas the amount of information should be equal at p values of 0.25 and 0.50, Kendall (1973) found more observing responses when the probability of reinforcement was 0.25 than when it was 0.50 or 0.75. Further, both Steiner (1970) and Eckerman (1973) obtained more observing behavior at values of 0.10 and 0.13, respectively, than predicted by Equation 2.

Thus, attempts to demonstrate changes in preference as a function of amount of information, regardless of how defined, are as yet equivocal. To some extent, inconsistencies in the results may be due to the procedures employed. With the choice techniques, where preferences have not been well predicted by H , the outcomes have been two different schedules of positive reinforcement. Subjects might well be able to discriminate between these schedules by means other than the informative stimuli. For example, in Hendry's (1969) experiment, where pigeons chose between mixed and multiple FR 90 FR 10 schedules, the FR 90 schedule would be uniquely signalled if the tenth response were unreinforced. Rilling and McDiarmid (1965) showed that pigeons can easily discriminate between such different FR schedules without the addition of correlated stimuli. In addition, choice of the informative or noninformative key was measured with concurrent FR 1 (Bower *et al.*, 1966) or FR 10 (Hendry, 1969) schedules. Pigeons responding

on concurrent FR schedules tend to distribute almost all of their pecks on the preferred key (Herrnstein, 1958), in which case gradations in preference may have been obscured.

With the observing response techniques, another type of confound exists: rate of reinforcement changes with amount of information. For example, as information is reduced from 1.0 to 0.72 bits (from Equation 1), the amount of reinforcement is reduced by 20%. Thus, reduction in observing behavior could have been due to reduction of the facilitatory effects of primary reinforcement.

In the present experiment, these problems were avoided through the use of concurrent variable-interval schedules in the choice link. Reinforcement and blackout were the outcomes in the terminal links, and amount of information (varied over a considerable range) accompanied the same change in the probability of reinforcement for both informative and noninformative links. Preference for the informative, terminal link was measured by the distribution of responses during the choice link.

METHOD

Subjects

Five male, White Carneaux pigeons, all experimentally naive, were maintained at 80% of their free-feeding weights.

Apparatus

A standard sound-insulated chamber (Gerbrands Co.) contained two translucent response keys mounted 8.9 cm apart, each requiring a force of 0.10 N to be activated. The response keys could be transilluminated from behind with white, blue, yellow, red, or green light. Pecks on the response keys during the initial link (both keys illuminated with white light) produced an auditory feedback click by operating a 110-V ac relay. A food hopper situated between and below the keys provided access to Purina Pigeon Checkers. When operated, the hopper was illuminated by two 7-W white lights. General chamber illumination was provided by two 7-W white lights (GE 1829) mounted on the ceiling. White noise was continuously present and electromechanical equipment was located in an adjacent room.

Procedure

A modified autoshaping technique (Brown and Jenkins, 1968) was used to train the pigeons to peck the response keys. Once reliable responding was established, the pigeons were placed on the concurrent-chain schedule schematized in Figure 1.

In the initial link, both keys were transilluminated with white light. Pecks produced an audible feedback click. Entrance into the ter-

Fig. 1. Diagram of the concurrent-chain procedure used in the present experiment. The upper portion indicates the sequence of events when a response on the left, initial-link key provided entrance into the noninformative terminal link. The lower portion indicates the sequence of events when a response on the right, initial-link key provided entrance into the informative terminal link.

minal links was arranged by two independent VI timers on a concurrent variable-interval 1-min variable-interval 1-min schedule (*conc VI 1-min VI 1-min*). The actual intervals used were derived from the distribution suggested by Fleshler and Hoffman (1962). When such entrance was scheduled by either VI timer, it stopped operating, but the other VI timer continued to operate. The next response on the appropriate key produced the terminal-link stimulus associated with that key and the other key was darkened. During a terminal link, both VI timers stopped. The relative rate of responding on the two initial-link keys was the measure of preference for the informative terminal link.

When the peck that gained access to the terminal link was on the left key, the noninformative link was entered. The response key turned yellow (except under control conditions described below) and the other key was darkened. Thirty seconds later, the trial ended with either reinforcement (4-sec access to the checkers) or blackout (4 sec with all lights extinguished). Any peck during the final 25 sec of the trial postponed the outcome until 25 sec passed without a response. At the end of the trial outcome, both keys were re-illuminated with white light indicating the beginning of the next trial in the initial link.

When the peck gaining access to the terminal link was on the right key, the informative link was entered. One of two colors appeared (except as noted below) and the other key was darkened. If reinforcement was the scheduled outcome, the key was illuminated red (for three birds) followed 30 sec later by 4-sec access to food. If the trial was scheduled to end with 4 sec of blackout, the key was illuminated green for 30 sec. Keylight colors were reversed for the other two birds. As in the noninformative link, pecks during the final 25 sec also postponed the outcome until 25 sec passed without a key peck. At the end of the trial, the initial link was re-instated.

The probabilities of reinforcement (*p*) were: 0.04, 0.10, 0.20, 0.40, 0.50, 0.60, 0.80, 0.90, 0.96, and 1.00. Blackout occurred with probability 1-*p*. The order of conditions, different for each bird, is shown in Table 1. Each bird remained on each condition until the following criteria for stability were attained: (a) the bird was on the condition for at least 28 days; (b) on the twenty-eighth day and every day thereafter until stability had been reached, the last 15 days were divided into three successive blocks of five sessions each, and the medians of these blocks showed neither an upward nor a downward trend, *i.e.*, neither $Md_1 < Md_2 < Md_3$ nor $Md_1 > Md_2 > Md_3$; and (c) there was no

Table 1

Number of sessions given each bird at each value of *p* (probability of reinforcement). Numbers in parentheses give the order in which conditions were studied for each bird. Values of *H* for each condition as calculated according to Equations 1 and 2 are also given.

<i>p</i> Values	<i>H</i> Eq. 1	<i>H</i> Eq. 2	Bird				
			31	32	33	34	35
0.04	0.242	0.186	41 (8)	33 (8)	358 (9)	39 (8)	50 (9)
0.10	0.469	0.332	67 (3)	39 (3)	28 (6)	33 (4)	33 (5)
0.20	0.722	0.464	33 (6)	37 (5)	29 (4)	50 (2)	75 (2)
0.40	0.971	0.529	33 (5)	52 (6)	30 (2)	39 (3)	41 (6)
0.50	1.000	0.500	30 (1)	56 (1)	84 (1)	59 (1)	42 (1)
0.60	0.971	0.442	96 (4)	29 (2)	28 (7)	46 (5)	29 (4)
0.80	0.722	0.258	41 (2)	34 (4)	30 (5)	28 (6)	34 (7)
0.90	0.469	0.137	109 (7)	28 (7)	44 (3)	33 (7)	42 (3)
0.96	0.242	0.057	180 (9)	28 (9)	56 (8)	29 (9)	44 (8)
1.00	0.000	0.000	81 (10)	82 (10)	175 (10)	70 (10)	33 (10)
1.00 ^A	0.000	0.000	34 (11)	84 (11)	—	41 (11)	31 (11)
0.50 ^B	0.000	0.000	84 (12)	59 (13)	73 (11)	135 (13)	45 (12)
0.50 ^C	0.000	0.000	74 (13)	28 (14)	—	84 (14)	86 (14)
0.50 ^D	1.000	0.500	102 (14)	126 (12)	105 (12)	53 (12)	38 (13)

^AColors reversed sides.

^BRed and green uncorrelated with outcomes.

^CYellow and blue on left; red and green on right—all uncorrelated with outcomes.

^DReturn to baseline: red and green correlated with outcomes; yellow on left.

trend during the final five days. The probability of reinforcement (and blackout) was always the same for both the informative and noninformative links at each condition, the only difference between links being that stimuli correlated with outcomes were provided in the right (informative) terminal link.

Sessions were conducted seven days a week, with each session lasting until 50 outcomes were obtained. The sequence of reinforcement and blackout outcomes was determined by a probability randomizer, the only constraint being that the session had to end with the correct probability values for reinforcement (p) and blackout ($1 - p$).

Control Conditions

Control conditions were given to test whether preferences were based on factors other than the information provided by the correlated stimuli. In one condition, $p = 1.00$, the key colors switched sides so that yellow now appeared on the right and red (or green) on the left. A second control condition made the red and green stimuli on the right uncor-

related with the outcomes, thus rendering them noninformative. As a final control condition, the yellow for the left terminal link was replaced by random alternations of yellow and blue, both uncorrelated with outcomes. This tested whether choice in the initial link had been affected by the presentation of two colors in the right terminal link, regardless of their correlation with outcomes, while only one color was presented in the left terminal link.

Before beginning the experimental conditions, all birds were studied at a probability of reinforcement of 0.50, with both red and green keylights uncorrelated with outcomes presented in *both* terminal links. This tested for any initial side bias. The median relative rates for the right link from the last five sessions for Birds 31 through 35 were, respectively, 0.507, 0.512, 0.596, 0.465, and 0.444.

RESULTS

Median relative rate during the free-choice, initial links (percentage of pecks on the right key) from the last five sessions at each value of

Fig. 2. Relative rate (percentage of pecks on the right, informative key) during the initial links for each pigeon. The points are the median rates from the last five sessions at each value of p (probability of reinforcement). The open square at 1.00 represents median relative rate when key colors reversed sides. At $p = 0.50$, open circles represent rate when red and green key colors were uncorrelated with outcomes; open triangles represent red and green on the right, and yellow and blue key colors presented on the left, all uncorrelated with outcomes; filled circles represent the redetermination of relative rate when red and green were again made informative and only a yellow light appeared on the left. The lower-right function is the mean of the five individual functions.

p for each pigeon are shown in Figure 2. Relative rate in the initial link is the measure of preference for informative stimuli presented in the right terminal link. Points above the 0.50 line indicate preference for the right terminal link in which the informative stimuli were presented. As can be seen, all five pigeons showed a marked preference for the informative link. Preferences were greatest at p values of 0.40 to 0.80, with only a slight decrease at values of 0.20, 0.90, and 0.96. A greater decrease in preference occurred at values below 0.20. The functions can be characterized as asymmetrical, inverted "U" functions. Higher preferences were shown for the larger of the complementary p values in 17 of the 20 possible comparisons.

Strong position and/or color preferences were also evident. There is no uncertainty as to outcome at a p value of 1.00, yet four of the birds showed a higher relative rate for the right key. When the key colors switched sides for four birds, so that yellow now appeared on the right and red (or green) on the left, all four birds reduced their preference for the right link, with one bird showing indifference and another reversing its side preference. In all five cases when the red and green key colors were made uninformative (no correlation be-

tween color and outcome) and the probability of reinforcement was 0.50, the preference for the right key, though still apparent, was substantially lower than when the colors were informative. Furthermore, when the left terminal link produced both yellow and blue key colors (both uncorrelated with outcomes) and the right link produced the uncorrelated red and green, preference of two birds studied on this condition declined slightly further. A return to initial conditions, $p = 0.50$ with red and green informative, substantially increased preference for the informative link for all birds.

Figure 3 shows, for each pigeon, the absolute rate of responding on the left and right initial-link keys at each p value from which relative rates were calculated. These response rates were obtained by dividing the total number of responses made to each key separately by the total time spent in the initial link. Rate of response on the left key (leading to the non-informative terminal link) remained relatively constant across all p values. The rate of response on the right key, however, is very similar to the relative rate functions shown in Figure 2: the highest rates were at the intermediate p values; rate decreased for values of 0.04, 0.10, and 1.00; little decrease in rate is

Fig. 3. Absolute rate of response on the left and right initial-link keys for each bird at each value of p for sessions shown in Figure 2. The lower-right function is the mean of the five individual functions.

shown at values of 0.90 and 0.96. Response rates on the right key, therefore, appear to be almost wholly responsible for the preference functions obtained.

To determine the relationship between choice in the initial link and H , average amount of information, the mean relative rate during the initial link at each p value shown in Figure 2 was replotted. According to Equation 1, complementary p values result in identical H values. Consequently, the mean relative rate can be plotted as a function of H , separately for the upper and lower halves of the probability continuum. Figure 4 shows that preference was related to H , but not equally so, for values above and below 0.50. Plotting this function according to Equation 2 would show little congruence between obtained and predicted values, since it predicts greater preferences for p values below 0.50 than for those above 0.50.

Responses during the final 25 sec of either terminal link reset a timer, thus postponing the outcome. This procedure effectively suppressed responding to the key. The amount of time spent in the left and right terminal links was computed for each pigeon separately, and the median of the last five sessions on each condition was obtained. The percentage increase in time spent in both the left and right terminal links over the minimum time possible never varied by more than 1%. Thus, there was no significant responding during either terminal link.

Direct observations and videotapes of the birds showed that the pigeons did behave differently, however, when the terminal links were entered. Upon entering the left, nonin-

formative link the birds initially moved around the chamber and, as time to the outcome approached, began pecking the side walls or feeder. This same behavior was observed when the right, informative link was entered only if the key color signalling reinforcement appeared. When the color signalling blackout appeared, the pigeons continued to move around the chamber and face away from the keylight, often pecking the floor, and often making cooing sounds.

DISCUSSION

Clearly, the presentation of stimuli correlated with consequent outcomes has very potent effects on pigeons' preferences. With the probability of reinforcement set at 0.50, preferences for the informative link ranged from 0.792 to 0.918, even though both the informative and noninformative links provided equal rates of primary reinforcement.

Preferences for informative stimuli were greater at p values above 0.50 than for their complementary values. If preference is determined by amount of information, by one definition of H (Equation 1) preferences should have been symmetrical around the 0.50 value; by another definition (Equation 2, where positive information is assumed to be more valuable than negative information), preferences should have been skewed in the direction of lower p values. Although the obtained results do not rule out the possibility of a third definition, where negative information is assumed to be more valuable than positive information, it is more likely that H is not the sole determinant of pigeon choice behavior.

One factor that may interact with H is rate of reinforcement. Reinforcement could in itself excite pecking, irrespective of which terminal link provided reinforcement on a particular trial (*i.e.*, whether obtained during the informative or noninformative link). Such excitation might reveal itself primarily on the preferred key (*i.e.*, the key leading to the informative link). In this way, the addition of both effects would account for the asymmetry found. Response rates during the initial link were fairly constant on the key leading to the noninformative link, while rates on the key leading to the informative link were higher at the higher p values than at the lower p values. If responding due to reinforcement rate added

Fig. 4. Mean relative rate for the informative key during the initial links as a function of amount of information, H . The solid line represents relative rates for p values above 0.50; the dotted line represents relative rates for p values below 0.50.

to responding due to amount of information, then not only would absolute rates be higher at p values above 0.50 than for their complementary values, but also slope differences would be evident when relative rate is plotted as a function of H (Figure 4). Relative rates for p values below 0.50 did show a steeper slope as H increased (amount of information increases along with amount of reinforcement) than for p values above 0.50, where amount of information decreases as amount of reinforcement increases. To control for the effects that changes in the overall rate of reinforcement might have on choice, one would need to hold the rate of reinforcement constant while varying only the probabilistic relation between the stimuli and the outcomes.

Another possibility is that the secondary reinforcing properties of the stimuli paired with the outcomes interact with H , since as the probability of reinforcement increases so too does the strength of secondary reinforcement. However, to account for the observed results it must be assumed (Wyckoff, 1959) that the function relating the secondary reinforcement value of a cue to the probability of reinforcement in its presence is positively accelerated. In other words, the secondary reinforcing properties of cues associated with the informative link must be stronger than those associated with the noninformative link, with even greater differences in secondary reinforcement associated with the correlated cues at the higher p values. The additional secondary reinforcement associated with the correlated cues could then combine with information value, thus leading to higher preferences at the larger of the complementary p values. In that case, the combination of information value and secondary reinforcement produces higher preference at the larger of the complementary p values.

Unfortunately, once it is assumed that H is not the sole determinant of preferences, almost any result can be explained through judicious manipulation of the relative importance of other factor(s). It would seem more parsimonious to re-examine the need for including the mathematical measure of information, the bit, at all in accounting for the preferences observed. One possibility is that the bit is the wrong metric for establishing a pigeon's choice behavior. In a more fundamental sense, however, it may simply be wrong to assume that

it is the information provided by only a positive signal that reinforces and maintains behavior (Wilton and Clements, 1971; see Equation 2). As noted by others (Eckerman, 1973; McMillan, 1974) such a viewpoint ignores the context in which the stimulus occurs, and without a context, the concept of information seems largely meaningless.

Given the gross preferences for informative over noninformative stimuli, what could be the importance of information for the pigeon? A possible source of the value of informative stimuli is their function as discriminative stimuli for various activities. The videotapes and observations of the pigeons clearly indicated that when the informative stimulus signalling reinforcement was presented, the birds initially engaged in behaviors unrelated to food delivery. Then, as time to reinforcement approached, pecking (at the walls, feeder, *etc.*) became highly probable. This same sequence of behaviors was observed during the noninformative stimuli. However, when the informative stimulus signalling blackout was presented, pre-outcome pecking was not observed. The distinction between pecking and other behaviors fits the distinction made by Staddon and Simmelhag (1971) between terminal responses, which increase in frequency as the probability of reinforcement increases, and interim activities, which are highest when reinforcement probability is lowest. As reported by Staddon and Simmelhag, the terminal response occurring most often was pecking, while most frequent interim activities included wing flapping, movement along the wall, and turning away from the magazine area. Informative stimuli may have value because of what they permit the animal to do during the delay period. When a stimulus signals blackout, the animal can engage in interim activities, while a stimulus signalling reinforcement allows the organism to perform appropriate terminal responses. Noninformative stimuli do not permit such differentiation of behavior.

Our analysis would account for apparent bias toward positive or negative information in terms of variations in value of interim and terminal activities. If we assume that terminal responses before food increase the value of the food situation and, hence, the terminal link during which they occur, and that interim responses (cooing, preening, *etc.*) are to some extent intrinsically reinforcing, we may con-

struct the following hierarchy of terminal links:

- (1) Food preceded by terminal responses.
- (2) Food preceded by interim responses.
- (3) Interim responses' intrinsic value (followed by blackout).
- (4) Terminal responses' intrinsic value (followed by blackout).

Informative stimuli ensure that the pigeon will obtain the higher valued items (1) and (3) on food and blackout terminal links and avoid items (2) and (4). Noninformative stimuli will force the pigeon to experience the lower-valued items (2) and (4) at least occasionally. As food gains in relative value (*i.e.*, when pigeons are hungrier) the signal for food becomes more important and a bias for "positive" information may be found. As interim responding gains in relative value (*i.e.*, by making the chamber larger) the signal for blackout will become more important and the pigeons may show a bias for "negative" information.

This analysis also predicts that as the opportunity to respond differentially in the terminal link is removed, the value of information *per se* will decrease and choice in the initial link should move toward indifference.

REFERENCES

- Bloomfield, T. M. Reinforcement schedules: contingency or contiguity? In R. M. Gilbert and J. R. Millenson (Eds), *Reinforcement: behavioral analyses*. New York: Academic Press, 1972. Pp. 165-208.
- Bower, G., McLean, J., and Meacham, J. Value of knowing when reinforcement is due. *Journal of Comparative and Physiological Psychology*, 1966, **62**, 184-192.
- Brown, P. L. and Jenkins, H. M. Auto-shaping of the pigeon's key-peck. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 1-8.
- Dinsmoor, J. A., Browne, M. P., and Lawrence, C. E. A test of the negative discriminative stimulus as a reinforcer of observing. *Journal of the Experimental Analysis of Behavior*, 1972, **18**, 79-85.
- Dinsmoor, J. A., Flint, G. A., Smith, R. F., and Viemeister, N. F. Differential reinforcing effects of stimuli associated with the presence or absence of a schedule of punishment. In D. P. Hendry (Ed), *Conditioned reinforcement*. Homewood, Illinois: Dorsey Press, 1969. Pp. 357-384.
- Eckerman, D. A. Uncertainty reduction and conditioned reinforcement. *The Psychological Record*, 1973, **23**, 39-47.
- Fleshler, M. and Hoffman, H. S. A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, 1962, **5**, 529-530.
- Garner, W. R. *Uncertainty and structure as psychological concepts*. New York: Wiley, 1962.
- Hendry, D. P. *Reinforcing value of information*. NASA Technical Report 65-1, Space Research Laboratory, University of Maryland, 1965.
- Hendry, D. P. Reinforcing value of information: fixed-ratio schedules. In D. P. Hendry (Ed), *Conditioned reinforcement*. Homewood, Illinois: Dorsey Press, 1969. Pp. 300-341.
- Hernstein, R. J. Some factors influencing behavior in a two-response situation. *Transactions of the New York Academy of Sciences*, 1958, **21**, 35-45.
- Jenkins, H. M. and Boakes, R. A. Observing stimulus sources that signal food or no food. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 197-207.
- Kendall, S. B. Effects of two procedures for varying information transmission on observing responses. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 73-83.
- McMillan, J. C. Average uncertainty as a determinant of observing behavior. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 401-408.
- Mulvaney, D. E., Dinsmoor, J. A., Jwaideh, A. R., and Hughes, L. H. Punishment of observing by the negative discriminative stimulus. *Journal of the Experimental Analysis of Behavior*, 1974, **21**, 37-44.
- Prokasy, W. F., Jr. The acquisition of observing responses in the absence of differential external reinforcement. *Journal of Comparative and Physiological Psychology*, 1956, **49**, 131-134.
- Rilling, M. and McDiarmid, C. Signal detection in fixed-ratio schedules. *Science*, 1965, **148**, 526-527.
- Segal, E. F. Induction and the provenance of operants. In R. M. Gilbert and J. R. Millenson (Eds), *Reinforcement: behavioral analyses*. New York: Academic Press, 1972. Pp. 1-34.
- Shannon, C. E. and Weaver, W. *The mathematical theory of communication*. Urbana: University of Illinois Press, 1949.
- Staddon, J. E. R. and Simmelhag, V. L. The "superstition" experiment: a reexamination of its implications for the principles of adaptive behavior. *Psychological Review*, 1971, **78**, 3-43.
- Steiner, J. Observing responses and uncertainty reduction: II. The effect of varying the probability of reinforcement. *Quarterly Journal of Experimental Psychology*, 1970, **22**, 592-599.
- Wilton, R. N. and Clements, R. O. The role of information in the emission of observing responses: a test of two hypotheses. *Journal of the Experimental Analysis of Behavior*, 1971, **16**, 161-166.
- Wyckoff, L. B., Jr. Toward a quantitative theory of secondary reinforcement. *Psychological Review*, 1959, **66**, 68-78.

Received 17 February 1976.

(Final Acceptance 30 September 1976.)