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AVERAGE UNCERTAINTY AS A DETERMINANT OF OBSERVING BEHAVIOR[1]

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After discrimination training on a multiple variable-interval extinction schedule of food reinforcement, pigeons were placed on the uncued or mixed version of the same schedule and allowed to make an optional "observing response" that converted the uncued schedule to the corresponding cued schedule by providing a 20-sec exposure to the appropriate discriminative stimulus. The schedule consisted of one hundred 40-sec components, and the probability that any one of them would be a variable-interval component was systematically varied between 0.00 and 1.00. The results showed that the amount of observing behavior was an inverted "U" function of the probability of the variable-interval component. Few observing responses occurred at probabilities of 0.00 or 1.00, and maximum responding occurred at a value less than 0.50.

In an "observing-response" procedure, an organism is given an option of responding under a reinforcement schedule whose components are not distinguished by different stimuli, *e.g.*, an uncued or mixed schedule, or of responding under stimulus conditions that do distinguish between the different components of the reinforcement schedule, *e.g.*, a cued or multiple schedule. The optional response that converts the uncued schedule to the corresponding cued schedule is called an "observing response" (*cf.* Prokasy, 1956; Wyckoff, 1952).

Wyckoff (1952, 1969) showed that observing behavior was strengthened when the discriminative stimuli produced by the observing response were reliably correlated with the reinforcement schedule components, but when the correlation was eliminated, the observing performance was disrupted. Experiments by Kelleher (1958), Kelleher, Riddle, and Cook (1962), Prokasy (1956), and Steiner (1967, 1970) have confirmed Wyckoff's original finding and have extended its generality in studies that have manipulated parameters of the reinforcement schedule.

Wyckoff suggested that observing responses are reinforced by the stimuli produced to the extent that these stimuli control performance of another response. This approach derives from the "discriminative stimulus" hypothesis of conditioned reinforcement (Keller and Schoenfeld, 1950; Skinner, 1938). An alternative account, offered by Prokasy (1956), assumes that observing responses occur because the change in stimulus conditions before reinforcement allows appropriate "preparatory responses" to occur. These preparatory responses are presumed to modify, in some way, the effect of the reinforcing stimuli that follow. Dinsmoor's group has suggested a third approach, concluding that observing responses are maintained solely by production of the stimulus that is positively correlated with food availability (Dinsmoor, Browne, and Lawrence, 1972). According to their view, the positive stimulus is a conditioned reinforcer because of its positive relationship to food.

A large portion of the observing-response literature has adopted one of the accounts

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outlined above as an explanatory basis. Several other papers, however, (Hendry, 1965, 1969; Steiner, 1967, 1970) have pointed to an additional possible account of observing behavior, namely, that the information-producing characteristic of the observing response may be the important variable controlling acquisition and maintenance of the behavior. As Eckerman (1973) pointed out, such an "information hypothesis" owes much of its appeal to the fact that behavioral procedures can be quantified in the terms of information theory (Garner, 1962).

The metric most often used to quantify information evolved from the work of Shannon (Shannon and Weaver, 1949) and Wiener (1948), and specifies the amount of information produced when one of several possible events occurs, each event having a fixed probability; in addition, the metric specifies the average uncertainty as to which of the possible events will occur on a given trial. In a situation where N alternative events could occur, the average uncertainty as to which event will occur (conventionally symbolized as H, and using the *bit* as the measurement unit) is given by the equation

$$H = \sum_{i=1}^{N} p_i \log_2 1/p_i \tag{1}$$

where p_i represents the fixed probability for each possible event, 1 through N (*cf.* Luce, 1960).

Thus, to consider an example, Wyckoff placed pigeons on an uncued schedule of food presentation in which 30-sec components with food available alternated equiprobably with 30-sec extinction components. The procedure may be described in terms of the amount of information produced when the observing response occurred (using Equation 1), or in terms of average uncertainty, similarly computed, as to which component is in effect in the absence of an observing response. Clearly, it would have been possible to manipulate H by varying the probabilities of the two schedule components. Such an experiment deserves consideration in light of suggestions by Hendry (1965, 1969) and Steiner (1967, 1970) that the amount of observing behavior to produce cues associated with the various components of a reinforcement schedule will be determined by the average uncertainty as to which component is in effect; the greater the uncertainty, the greater the responding to produce cues that reduce the uncertainty. According to this reasoning, when the reinforcement schedule consists of two alternative components, observing behavior should be a symmetrical, inverted "U"-shaped function of the probability of one of the components, because H also varies in that way.

In the present experiment, pigeons were trained to make observing responses that produced the stimuli correlated with the alternative variable-interval and extinction components of a multiple schedule of food availability. The probability of the variable-interval component was then systematically manipulated from zero to one in order to assess the control of the probability variable, and thus, average uncertainty, over observing behavior.

METHOD

Subjects

Six male White Carneaux pigeons were maintained at 80% of their free-feeding weights, and exposed daily to the experimental procedures. Birds 306, 309, and 310 had served in similar experiments. Birds 305, 308, and 405 were naive.

Apparatus

The experimental chamber measured 25 by 30 by 35 cm with two 2-cm Gerbrands pigeon keys mounted on the front wall, 20 cm above the floor, and separated by 10 cm. Both keys were adjusted to allow any peck exceeding 15 to 20 g (0.15 to 0.2 N) in force to be detected. A grain hopper was centered in the front wall, 5 cm above the floor. The keys could be illuminated by GE 1820 lightbulbs (24 V dc) projected through red, white, or green lens caps. The chamber was housed in a sound-reducing compartment, with continuous white noise present. Scheduling and recording equipment were located in an adjacent room. The schedule component probabilities were manipulated by a paper-tape reader that decoded a predetermined series of schedule components punched on tape.

Procedure

Preliminary VI training. In the first session for the three naive subjects, key pecking was shaped to the right key (subsequently referred to as the "food key") with grain; the left key was covered. In the second session, all subjects were allowed one hundred 5-sec reinforcements on a variable-interval 20-sec (VI 20-sec) schedule. In the next few sessions, the mean interreinforcement interval was gradually increased within and across sessions to 70 sec (VI 70-sec), and session duration was fixed at 66.7 min (4000 sec).

Discrimination training. After 40 sessions of preliminary VI training, the session was divided into one hundred 40-sec periods or components. During a randomly chosen one-half of these components, the VI schedule was in effect; the 50 remaining were extinction (EXT) components. For all subjects, a white light (S+) on the food key signalled VI periods and a red light (S—) signalled EXT. Under these conditions, the reinforcement schedule for pecking the food key was a *mult* VI 70-sec EXT schedule, with the probability (p) of VI being 0.50.

Discrimination training was continued until each subject achieved a discrimination criterion in which the ratio of food-key response rate during S— to food-key response rate during S+ was less than 0.10 for 10 successive days.

Observing-response procedure. After discrimination training, the left key (subsequently called the "observing key") was uncovered, and the observing-response procedure begun at the initial p value for each subject, as shown in Table 1. Each session of this procedure started with a green light (mixed stimulus) projected on both keys, and a *mix* VI 70-sec EXT schedule in effect on the food key, with p specifying the proportion of VI components in the *mix* schedule. This schedule was like the *mult* schedule used during discrimination training, except for the absence of discriminative stimuli indicating whether VI or EXT was in effect. Under these circumstances, failure to peck the observing key resulted in the food-key schedule remaining a *mix* schedule indefinitely. On the other hand, a peck on the observing key defined an observing response, and turned off the *mix* schedule stimuli on both keys. Each observing response produced a 20-sec exposure on the food key to S+ or S—, whichever was appropriate. If the *mix* schedule component in effect at the occurrence of the observing response was VI, S+ appeared on the food key; if EXT was in effect, S— appeared. If the reinforcement schedule changed during the 20-sec following an observing response, the stimulus on the food key changed accordingly. Additional pecks on the observing key during S+ and S— were recorded, but had no scheduled consequence. A 2-sec changeover delay (*cf.* Catania, 1966) prevented food reinforcements from occurring immediately after an observing response. As each individual subject's observing-response performance stabilized, the observing key was again covered, a new value of the probability of the VI component was selected, and the animal was given 10 retraining sessions with the new value of p, five on the multiple schedule and five on the mixed schedule. These retraining sessions were used each time p was changed to provide both *mult* and *mix* schedule baselines before evaluating the observing performance. This general pattern of *mult-mix* schedule retraining at different values of p, followed by exposure to the observing procedure, was con-

Table 1

Number of sessions given each subject in each stage of the experiment. Columns for observing-response procedures are headed by both the probability of the VI schedule and the value of H produced by that probability condition. Numbers in parentheses give the order in which conditions occurred for each subject.

Subject	*Preliminary VI Training*	*Discrimination Training*	H *0.00*	*0.72*	*0.93*	*1.00*	*0.93*	*0.72*	*0.00*
			p *0.00*	*0.20*	*0.35*	*0.50*	*0.65*	*0.80*	*1.00*
306	40	29	10(2)	21(7)	21(5)	24(3)	12(6)	30(1)	28(4)
309	38	12	10(7)	15(2)	10(6)	19(4)	12(5)	23(3)	12(1)
310	38	35		27(2)		14(3)			11(1)
305	42	22	10(4)	21(5)	10(6)	12(1)	11(7)	10(3)	10(2)
308	39	21	10(6)	21(3)	11(5)	11(1)	16(2)	13(7)	34(4)
405	36	22	10(7)	28(2)	10(3)	15(1)	10(5)	10(6)	10(4)

tinued until each subject had been exposed to seven p values, with the exception noted below for Bird 310.

The primary measure of observing behavior in each session was the amount of time that each subject spent in the presence of the *mult* schedule stimuli, expressed as a percentage of that session's total duration. At each p value, an animal was exposed to the observing procedure for a minimum of 10 sessions. Stability was defined as the point where five consecutive sessions occurred with the percentage of time spent in the *mult* schedule from all five sessions within a range of 10 percentage points. All data presented here are based on means from these last five sessions. The number of sessions given each bird during preliminary VI training, discrimination training, and on the observing procedure at each p value is shown in Table 1.

Note that the number of observing responses per session can be directly derived from the percentage of the total session by doubling the percentage.

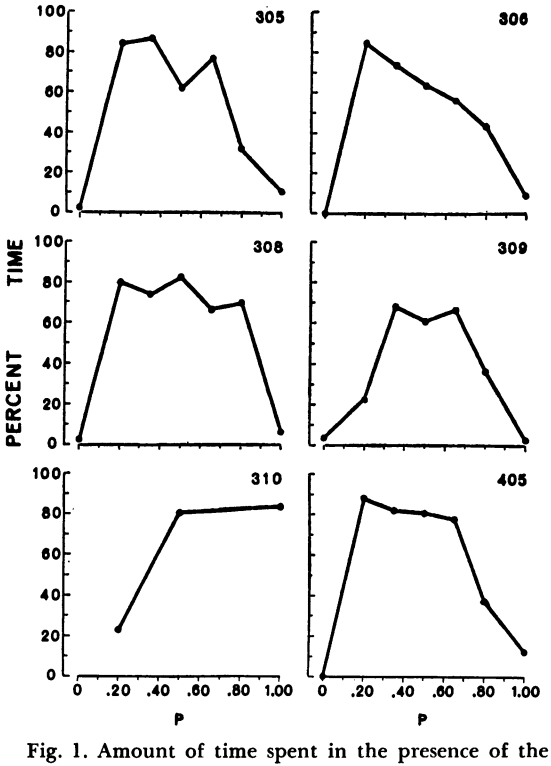

Fig. 1. Amount of time spent in the presence of the multiple-schedule stimuli expressed as a percentage of the total session duration at each probability value. Each data point is a mean of the last five sessions at that value.

RESULTS

The relationship between the amount of observing behavior maintained and the probability of the VI component is depicted in Figure 1 for each subject by the mean percentage of the total session time spent in the presence of the *mult* schedule stimuli at each value of p. For five animals, these functions are inverted "U" in shape, with few observing responses occurring at probabilities of 0.00 or 1.00; at intermediate probabilities, large amounts of observing behavior were obtained. More specifically, the inverted "U" functions were asymmetrical, tending to peak at $p < 0.50$. The single exception to this finding was the direct, negatively accelerated relationship between the observing response measure and p provided by Bird 310. Although Figure 1 shows data for Bird 310 at only three points along the probability continuum, other data points (not shown here) correspond very well with the function plotted in Figure 1. For example, at a probability of 0.10, Bird 310 made no observing responses and when data points at 0.50 and 1.00 were redetermined, the percentages were 76.3 and 80.6, respectively. Subsequently, 310 was placed on another procedure, and no further data are reported for it.

To determine the relationship between observing behavior and H, the data from all subjects, except 310, were combined, and the mean percentage of session duration spent in the presence of S+ and S− was computed at each p value. Moreover, since complementary p values result in identical H values, it is possible to plot the mean observing-response measure as a function of H, separately, for the upper and lower halves of the probability continuum. Figure 2 reveals that the average for all subjects of the percentage of session duration spent in the presence of the *mult* schedule stimuli was related to H in a linear fashion only for the range of probability values between 0.50 to 1.00, *i.e.*, when $p > 0.50$. When p was less than 0.50, the relationship was curvilinear with generally more time spent in S+ or S− at $H = 0.93$ than at $H = 1.00$. Thus, under the present procedure, the amount of observing behavior is proportional to average uncertainty about the schedule component that is in effect only when p exceeds 0.50; when p is less than 0.50, the observing-response

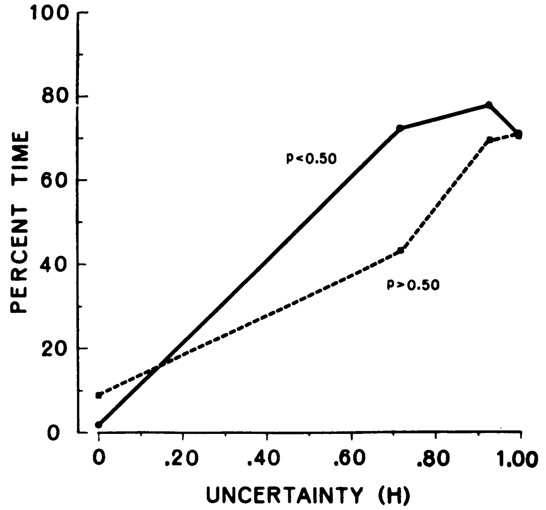

Fig. 2. Mean percentage of time spent in the presence of the multiple-schedule stimuli as a function of average uncertainty (*H*) across all animals except 310. The means are plotted separately for probability values above and below 0.50.

measure reaches a maximum at less than the maximal value of *H*.

During all of the observing-response procedures, food-key responding was controlled by the stimuli correlated with the three schedules of reinforcement: VI, EXT, and *mix* VI EXT. The data shown in Table 2 are (a) the response rates to S+ and S− from the last session of the original discrimination training, and (b) mean response rates in the presence of all three stimuli for the last five observing-response sessions at each *p* value.

The mean discrimination ratio for the last session of original discrimination training was 0.029 (range: 0.003 to 0.077). Comparison of food-key response rates in S+ and in S− during the observing-response sessions reveals that the strong differentiation of food-key responding produced by the original S+/S− discrimination training, and evidenced by resultant small discrimination ratios reported above, was sustained during all observing-response procedures. Responding in the presence of S− never exceeded 2.4 responses per minute (Table 2, Bird 308) and the ratio of S− food-key response rate to S+ food-key response rate never exceeded 0.036 (Table 2, Bird 310) across all animals and all probability values.

During observing-response sessions, food-key response rates during the mixed stimulus were

Table 2

Response rate during S+ and S− from the final session of discrimination training for each subject and response rate in the presence of S+, S−, and the mixed stimulus for the last five observing-response sessions at each *p* value.

Subject	*Stimulus*	*Original Discrimination*	p						
			0	*.20*	*.35*	*.50*	*.65*	*.80*	*1.00*
305	S+	96.6		72.5	47.5	83.5	57.0	55.4	53.5
	S−	0.6	0.3	1.1	0.1	0.7	0.5	0.6	
	Mix		0.0	8.7	17.8	35.6	29.6	51.1	48.3
306	S+	63.8		66.8	55.1	50.8	63.6	47.6	43.3
	S−	3.2	0.0	0.2	0.1	0.3	0.1	1.1	
	Mix		0.0	22.0	87.5	58.9	98.0	74.0	84.1
308	S+	56.1		73.4	80.9	81.8	76.1	65.7	70.5
	S−	1.1	0.0	2.4	0.1	0.2	0.7	0.1	
	Mix		0.0	17.9	34.9	18.1	51.0	61.3	72.1
309	S+	50.8		62.4	45.4	34.9	39.6	35.9	37.5
	S−	0.9	0.0	0.1	0.1	1.0	1.4	0.3	
	Mix		0.0	0.2	16.8	29.4	30.8	29.1	34.5
310	S+	48.7		83.8		55.0			47.5
	S−	3.7		0.6		2.0			
	Mix			0.3		5.0			3.0
405	S+	65.2		81.8		81.4			
	S−	0.2	0.0	0.1		0.1			
	Mix		0.0	18.0		10.5			
Mean	S+	63.5		73.5	57.2	64.5	59.1	51.2	50.5
	S−	1.6	0.1	0.7	0.1	0.7	0.7	0.5	
	Mix		0.0	11.2	39.2	26.3	52.3	53.9	48.4

frequently intermediate between S+ and S− rates, and, in addition, were an increasing function of p (Table 2). Since the overall reinforcement frequency that was available in the presence of the mixed stimulus also increased as p increased, the increasing mixed-stimulus response rate parallels an increasing reinforcement frequency in the presence of that stimulus.

DISCUSSION

The finding that the observing-response functions were not symmetrical, and therefore, that the observing-response measure was not a linear function of H for both halves of the probability continuum, cautions against the "information hypothesis" description of the quantitative relationship between observing behavior and H. This finding of asymmetry of effect had been indicated earlier, beginning with Hendry (1965), who studied the observing behavior of a chimpanzee whose lever pressing for food reinforcement was maintained on a complex multiple schedule that was itself composed of a tandem fixed-interval component and a mixed variable-ratio 100 extinction (*mix* VR EXT) component. Hendry varied the probability of the VR component within the *mix* VR EXT, using 10 values ranging from 0.10 to 0.90, and found that observing-response rate was an inverted "U" function of p, peaking at about 0.35. Eckerman (1973), using what he termed a "sequential choice procedure", found that pigeons preferred a *mult* FI 10-sec FI 60-sec over the analogous *mix* schedule. After much training with different values for the probability of the shorter FI, he found evidence that preference for the *mult* schedule conformed to an inverted "U" function of p with a peak at about 0.13. Kendall (1973, Experiment I) and Wilton and Clements (1971) reported experiments using novel procedures that also showed that observing behavior was stronger when $p < 0.50$. Specifically, Wilton and Clements compared $p = 0.20$ with $p = 0.80$ and found that the former condition maintained higher observing-response rates in pigeons. Kendall compared p values of 0.25, 0.50, and 0.75, and found 0.25 most effective in maintaining the observing behavior of pigeons. McMichael, Lanzetta, and Driscoll (1967) found similar results in rats using p values of 0.20, 0.50, and 0.80. The present paper extends these findings through a systematic exploration in several subjects of the entire range of the probability variable, rather than two or three isolated points.

Although the bulk of the evidence supports the conclusion of asymmetry of effect when p is manipulated, a theoretical basis for the phenomenon is not immediately evident. Wilton and Clements (1971) proposed a modified information hypothesis in which the assumption is made that observing responses are reinforced by the information provided by the positive stimulus alone. According to these authors, the term $p \log_2 1/p$, where p is the probability of S+, specifies the information given by that stimulus (*cf.* Garner, 1962). Eckerman (1973) concluded that his data were more aptly described by the single term $p \log_2 1/p$ than by Equation 1. To make the same comparison in the present study, the mean percentage of total session duration spent in the presence of the *mult* schedule stimuli was plotted as a function of p in Figure 3. Additionally, the term $p \log_2 1/p$ was evaluated for each p and plotted on the same axes with the highest points on the two curves made to coincide. Comparison of these curves shows that the empirical and theoretical functions are quite similar in shape. These data provide some confidence that observing behavior at various probability values corresponds to the quantity $p \log_2 1/p$, although a degree of caution must be used in viewing this average function. The primary concern stems from the fact that the mean percentage of time spent in the presence of the *mult* schedule stimuli at $p = 0.20$ is not grossly different from the percentage obtained at $p = 0.35$ (see Figure 3). Since these two p values resulted in similar amounts of observing, and since the present experimental design did not call for the study of small p values in the range 0.00 to 0.20, it is conceivable that the empirical function is not truly an inverted "U" function with both ascending and descending slopes, but rather, a decreasing function of p, discontinuous at $p = 0.00$. The present data do not allow a choice, but both Eckerman (1973) and Hendry (1965), the only authors who have studied small p values, reported evidence of ascending as well as descending slopes, suggesting that the present data would also have a pronounced descending slope between $p = 0.00$ and $p = 0.35$ had more values been used.

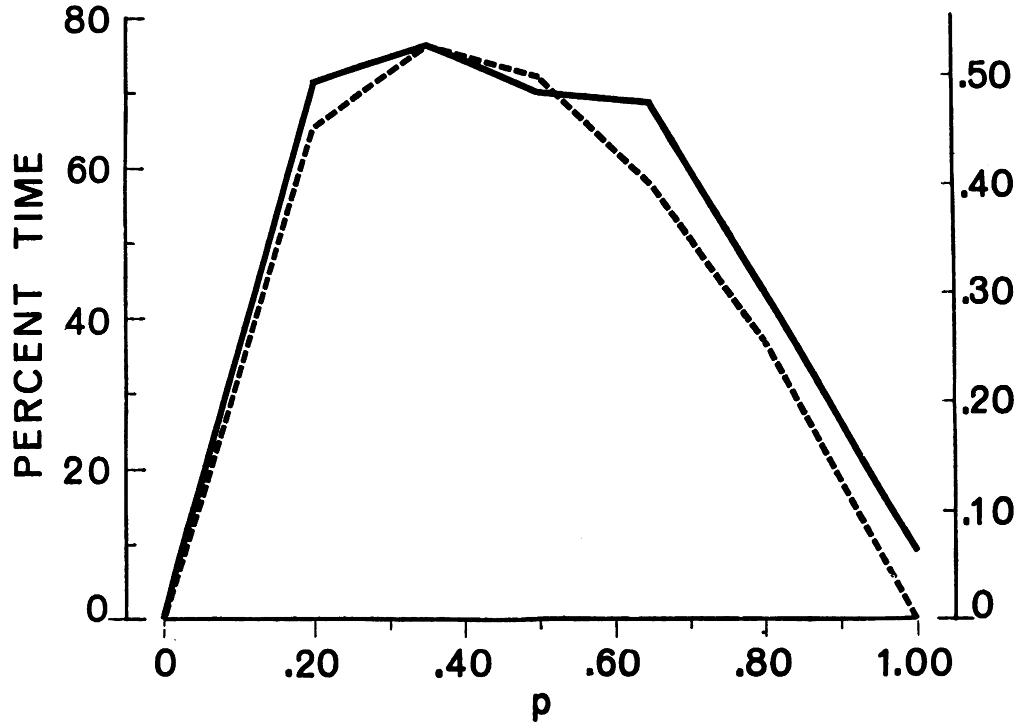

Fig. 3. Mean percentage of time spent in the presence of the multiple-schedule stimuli for all animals except 310 as a function of p (solid line), and a plot of the expression $p \log_2 1/p$ for the seven probability values studied (dashed line). See text for further explanation.

If the empirical function is a decreasing one, discontinuous at $p = 0.00$ (or some small, nonzero value), then a traditional conditioned reinforcement theory of observing behavior on the order of Dinsmoor *et al.*'s (1972) provides a straightforward theoretical treatment. Dinsmoor and his associates, as mentioned previously, vest all responsibility for the maintenance of observing behavior in the positive stimulus. The present value of $p = 0.00$ corresponds to extinction, where both food-key and observing behavior should disappear according to a traditional formulation. As p increases in value, the reinforcement frequency in the presence of the mixed stimulus increases, and approaches the reinforcement frequency in the presence of S+, the two becoming identical at $p = 1.00$. Therefore, according to the traditional account, the difference in conditioned reinforcing strength between the two stimuli should diminish as p increases. Thus, preference for the *mult* schedule, and therefore, observing behavior, should change in a discontinuous manner from no preference and no observing at $p = 0.00$ to maximal preference and maximal observing at $p = 0.20$, because 0.20 is the point in the present study where the difference in reinforcement frequency and, therefore, in conditioned reinforcement value between S+ and the mixed stimulus, is greatest. As the difference in conditioned reinforcing value between S+ and the mixed stimulus decreases (with increasing p values), observing behavior would be expected to decrease.

If the empirical function is truly inverted "U" in shape, then the theoretical account suggested by Wilton and Clements (1971) receives strong support at a descriptive level because of the close correspondence between the theoretical and empirical functions in Figure 3. However, some reservation must be held with regard to Wilton and Clements' (1971) interpretation of the term $p \log_2 1/p$ as the amount of information given by the positive stimulus without consideration of the context in which the stimulus occurs. Eckerman (1973) also questioned the appropriateness of the Wilton and Clements interpretation because most behavioral applications of information concepts require consideration of the entire array of possible signals in arriving at estimates of uncertainty or information. Thus, information is usually treated as a statistical parameter of a probability function defined on a set of alternative outcomes, not of an isolated element of the set (*cf.* Luce, 1960). In this regard, it is not clear how theoretical sense is made, nor empirical analysis extended, by labelling the mathematical term, $p \log_2 1/p$, as the amount of information given by a positive stimulus. A more fruitful approach might be to specify in greater detail the nature of the relationship between observing behavior and p, with particular emphasis on the small probability values.

The fact that food-key responding in the present study remained under stimulus control by S+ and S− during observing-response sessions at all values of the probability variable is indicated by the small ratios of S− response rates to S+ response rates. This finding of invariant stimulus control across all the probability conditions, whether observing responses were occurring frequently or rarely, suggests that factors other than the degree of discriminative control that stimuli exert over behavior are important in determining the conditioned reinforcing strength of the stimuli. The present experiment shows that the probability with which one of two components of a *mult* schedule occurs is one of the factors that determines the combined conditioned reinforcing strength of the *mult* schedule stimuli.

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