

Eye movements of monkeys during brightness discrimination and discrimination reversal*

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Eye movements of two stump-tailed monkeys were measured during performance on an easy and a difficult brightness discrimination problem with and without a relatively long fixation required at the beginning of each trial for purposes of calibration. The duration of an individual fixation of the discriminative stimuli was unrelated to most of the variables that were examined, including problem difficulty, response outcome, whether the S+ or the S- was fixated, and presence or absence of a long fixation at the beginning of a trial. Duration of fixation increased markedly, though temporarily, following reversal of the hard problem. The animals tended to do a minimal amount of scanning of the discriminative stimuli and to fixate most frequently on S+ before responding. In general, the results did not support an account of observing behavior in terms of conventional reinforcement.

Experimental psychologists have made extensive use of visual discrimination tasks in studying animal learning. Obviously, in order to learn such tasks, the animals must consistently look at the discriminative stimuli, yet relatively little is known about how they do this. A pioneering study in this area was carried out by Wyckoff (1951, 1952), who introduced the widely used term "observing response." An observing response may be defined as any response that exposes the animal to a discriminative stimulus.¹ Such responses should be distinguished from the subsequent instrumental choice responses which determine the outcomes (reinforcement or nonreinforcement) of trials. Wyckoff proposed that observing responses are strengthened and maintained by secondary reinforcement provided by the discriminative stimuli once they become differentially associated with primary reinforcement. Eye orientation is the most obvious and direct observing response in a visual task. However, the technical difficulties associated with measuring eye orientation, especially in rats and pigeons, which have been the most popular Ss in learning studies, led Wyckoff and most subsequent investigators to use what we might call "nonocular" observing responses, which, though less direct, were more easily measured. Thus, the animals were required to make certain arbitrary, E-defined responses, such as leverpresses, which would result in the exposure of the discriminative stimuli. Although there are exceptions (Dinsmoor, Brown, & Lawrence, 1972), in general the results of the studies involving such procedures (Premack & Collier, 1966; D'Amato, Etkin, & Fazzarro, 1968; Lieberman, 1972) raise serious questions about accounts of observing responses in terms of conventional reinforcement theory, such as Wyckoff's.

In recent years, several techniques have been developed for studying eye movements in monkeys

(Bagshaw, Mackworth, & Pribram, 1970; Fuchs, 1967), but relatively little systematic work has been reported as yet, especially on eye movements during visual discrimination learning. Oscar-Berman, Heywood, and Gross (1971) studied eye movements of rhesus monkeys during learning of two pattern-discrimination problems. They reported some systematic changes as learning progressed. An early tendency to spend more time looking at the stimulus display on one side rather than on the other tended to diminish with practice. Also, the animals tended to respond where they were looking and, increasingly, tended to spend more time looking at the positive stimulus than at the negative. Bagshaw, Mackworth, and Pribram (1970) reinforced normal and brain-operated rhesus monkeys for fixating for 2 sec on one of two stimuli differing in form. For the normal animals, over the course of a short period of practice, the duration of a fixation of the positive stimulus increased and the frequency of fixations that were completely off the stimulus display during a trial decreased.

The present report presents information on eye movements of stump-tailed monkeys while performing easy and difficult brightness discriminations and a reversal of the difficult discrimination. A variation of the well-known corneal reflection technique, involving a computer for recording the location of the reflection, was developed for this research (Schrier, Povar, & Vaughan, 1970, 1971). The aim of the research was to provide a base of information about eye movements during discrimination learning for purposes of further research as well as to add to our information about the function of observing responses during such learning.

METHOD

Subjects

Two wild-born female stump-tailed monkeys (*Macaca arctoides*), each about 4.5 years of age, served as the Ss (Herci and Tilda). On test days, each animal received about 90% of its

*This research was supported by the first author's Research Grant GB-18953X from the National Science Foundation.

normal daily ration in the form of 190-mg banana-flavored whole-diet pellets (Noyes) in the test situation and the remainder in the form of standard commercial monkey biscuits in the home cage. They were fed only enough to keep their weights constant or increasing slightly.

Apparatus

The apparatus has been described in detail in a prior publication (Schrier, Povar, & Vaughan, 1970), and thus only a general description will be given here. It consisted of three primary components: (a) a restraining chair, (b) a helmet, held in place by a mouth brace, on which were mounted stimulus presentation devices and equipment for obtaining the corneal reflection, and (c) a computer that controlled the experimental events and recorded eye orientation and choice responses. During testing, the animal was seated in the chair facing a panel in which were three response devices. These were three "pecking keys" (Lehigh Valley Electronics, Fogelsville, Pennsylvania) mounted behind 2.5-cm openings which were arranged in a horizontal line and spaced 6.5 cm apart center to center. They will be referred to as the center and side keys, respectively. The keys were located about 25 cm from the animal's head. Three stimulus presentation devices were mounted on the helmet, each consisting of a white pilot light shining through a 0.6-mm aperture. The three stimulus lights were located about 18 cm in front of the animal's left eye and were arranged in an inverted (base upward) equilateral triangle with 5-cm sides, which represents 15 deg of visual angle. The lowest light will be referred to as the center light, and the two upper lights will be called the side lights. The stimulus lights were mounted against a dull black background and were operated at a luminance of either 7.0 or 3.5 fL. The former level will be referred to as the bright and the latter as the dim stimulus luminance, and unless otherwise noted, reference to the operation of a stimulus light will indicate the bright luminance. Room illumination was provided by overhead fluorescent lamps.

Eye movements were recorded by monitoring the corneal reflection of a light source mounted on the helmet and focused on the animal's right eye. The corneal reflection was transmitted from a lens, also mounted on the helmet, to a special TV camera by means of a coherent fiber optics cable. The on-line computer sampled the location of the corneal reflection, as represented in the output signals of the TV camera, 60 times a second. For recording the location of the reflection, the computer representation of the TV field was divided into a 16 by 16 recording grid. A single fixation was defined as a series of TV frames during which the locus of the eye spot did not move more than one cell in the recording grid in either the horizontal or vertical direction. The mean location during such a series was taken as the location of the fixation. Each cell in the region of the grid corresponding to the locations of the experimental stimuli represented horizontal and vertical distances of approximately 3 deg of visual angle.

General Procedure

The animal was placed in the restraining chair and the helmet put on its head. The animal was allowed to work on the current problem while adjustments were made in the helmet-mounted equipment to obtain a suitable corneal reflection. Following this, the animal was left alone in the testing room for the remainder of the testing session, and the E observed the animal's behavior on closed-circuit TV and monitored the calibration of the system on the computer's oscilloscope in a separate control room. The monkeys were tested 5 days each week with a daily test session typically lasting about 2 h. A discrete-trial procedure was used, and approximately 500 trials were presented in each test session. Trials were separated by intertrial intervals chosen randomly from the following four values: 4, 6, 8, or 10 sec. A trial consisted of a calibration and a discrimination phase. The onset

of a 400-Hz tone signaled the beginning of the calibration phase. During the initial stages of the experiment, after a randomly selected interval (1, 2, 3, or 4 sec) following the onset of the tone, the center light was illuminated for 320 msec, while the tone remained on. The monkey had to operate the center response key within 1.5 sec after the onset of the center light to start the discrimination phase of the trial. If no response occurred within 1.5 sec, or if a response occurred during the tone but before the center light, the tone was terminated and a new intertrial interval was begun. During the 400-Hz warning tone, the animal tended to fixate the center light in anticipation of the brief center light illumination. Calibration was achieved by maintaining the superimposed recording grid in a constant position relative to these fixations on the center light region. During the later stages of the experiment, an additional procedure which will be referred to as the long calibration fixation (LCF) procedure was used. In this case, the center light came on only if the monkey made a fixation of at least 1 sec duration in the center light area during the warning tone (cf. Schrier, Povar, & Vaughan, 1971). If no fixation satisfying this criterion occurred within one of the randomly selected durations following tone onset, the tone was terminated and a new intertrial interval started. This procedure greatly increased the ease with which calibration was maintained because the E had much longer to observe the location of the fixations in the center light area than is permitted by the typical fixation duration of 150-200 msec.

One or both of the side lights were illuminated during the discrimination portion of the trial. Brightness differences always indicated which side key was correct. When the animal pressed one of these keys, the stimuli were turned off, reinforcement was delivered if the response was correct, and the next intertrial interval was started. The trial was terminated if the animal did not respond to one of the side keys within 3 sec. This was usually considerably more time than the animals needed.

After pretraining, both animals received the following problems in the order indicated: easy brightness problem (E1), hard brightness problem (H1), easy brightness problem with the LCF procedure (E2), hard brightness problem with the LCF procedure (H2), and reversal of the hard brightness problem with the LCF procedure (HR). For each problem, the animals were tested until there were 5 consecutive days (approximately 2,500 trials) without an improvement in daily performance level. This will be referred to as the "criterion period" in the remainder of the paper.

The pretraining stage lasted approximately 4 months, during which time the monkeys were trained to sit in the restraining chair, to operate a single response key, to accept the helmet and associated equipment, and to respond on the basis of one or more discriminative stimuli located on the helmet. The procedure was similar to that described before (Schrier, Povar, & Vaughan, 1970). On each trial of the easy problems, one of the stimulus lights was illuminated and the other was not. The illuminated side was positive. For the hard problems, both stimulus lights were illuminated, one at the dim level and the other at the bright level. During Problems H1 and H2, the brighter level was positive, and during Problem HR, the reverse was the case. The procedure for Problems E1 and H1 was identical to that for E2 and H2, respectively, except for the addition of the LCF condition.

The data analysis was concentrated on the visual behavior which occurred during the discrimination portion of the trials and was restricted to fixations on the side lights (discriminative stimuli). On the basis of an examination of the spatial distribution of fixations in this and the preliminary work (see Fig. 4 in Schrier et al. 1970, 1971), fixations on the side lights were defined as any that fell within one of two three-cell-wide by five-cell-high areas on the recording grid. Motion of the helmet produced by chewing of food pellets received on prior trials and vertical "play" in the helmet-mounted equipment probably accounts in part for the greater spread of recorded side

light fixations in the vertical direction. Ninety-one percent of all recorded fixations made by Herci and 59% of all recorded fixations by Tilda were located in the defined side light areas. Although there was no precise record of fixations on the manipulanda because they were not mounted on the helmet and, thus, were not in calibration, the data strongly suggested that the lower percentage of fixations in the side light areas found for Tilda was due to a high frequency of fixations on the manipulanda. This might account for some of the differences between her eye movement data and Herci's. Only trials for which a recordable reflection was present at least 80% of the time were analyzed. Excluding reversal trials, 23,942 trials were analyzed for Herci and 14,498 for Tilda. For Herci and Tilda, respectively, 9,365 trials and 7,739 trials were analyzed for the reversal procedure.

RESULTS

The hard problem was indeed harder than the easy problem; criterion performance level on Problems E1 and E2 taken together was 96% correct for Herci and 96% correct for Tilda. For Problems H1 and H2, criterion performance was 77% correct for Herci and 78% correct for Tilda.

One important measure in the analysis of eye movement data is the duration of individual fixations. Table 1 presents median durations of individual fixations on the side lights for a variety of conditions for the two stump-tailed monkeys of the present study and for one rhesus monkey observed previously under similar conditions, but without the LCF contingency (Schrier et al, 1970). Fixations that overlapped the beginning or end of the discrimination phase of a trial were excluded from the analyses of fixation duration. Median duration of fixation over all conditions of the experiment except the reversal was somewhat higher for Herci than for Tilda and the rhesus monkey. The distribution of fixation durations may be seen in Fig. 4. In general, as Table 1 suggests, the duration of individual fixations appeared to be little influenced by most of the variables that were examined, including problem difficulty, whether the left or right side light was positive, whether the positive or negative stimulus was fixated on, and, for the hard problems (the only case in which an appreciable number of errors occurred), whether or not the response was correct. One exception appeared to be a tendency for fixation durations in all three animals to differ depending on whether the left or right side light was being fixated on, with the difference in Herci's case being relatively large. However, it should be noted that the differences in durations seen in Table 1 are all rather small compared to the changes in duration that occurred following reversal, which will be described below. The median fixation durations with and without the LCF contingency (i.e., for Problems E1 plus H1 vs Problems E2 plus H2), also shown in Table 1, suggest that the addition of this procedure during the calibration phase had little, if any, effect on fixations on the discriminative stimuli during the discrimination phase. In general, differences in the various measures of eye movements between the precriterion and criterion

Table 1
Median Duration (in Milliseconds) of Individual Fixations on the Discriminative Stimuli During the Discrimination Phase of Trials for the Two Stumptailed Monkeys and a Rhesus Monkey Tested Previously (Schrier et al, 1970)*

Condition	Subject		
	Herci	Tilda	Rhesus
Overall	186	157	147
Easy Problems	171	159	145
Hard Problems	190	154	150
Left Positive	192	156	151
Right Positive	178	158	146
Left Fixations	159	149	160
Right Fixations	196	159	145
Hard Correct	191	155	147
Hard Incorrect	189	155	154
S+	186	149	—
S-	187	153	—
Without LCF	177	154	—
With LCF	188	162	—
Precriterion	189	152	—
Criterion	179	160	—

*The data are from the precriterion and criterion periods of Problems E1, E2, H1, and H2.

periods were small and not consistent in direction, and so the data for these periods have been combined.

Another important measure of visual behavior in this situation is the temporal pattern of fixations. For Herci, 52% of first fixations were on the left light, while 50% of all fixations were on the left light. For Tilda, 66% of first fixations were on the left light and 56% of all fixations were on the left light. The extensive training the animals received probably accounts for the relatively low observing response position preference (Oscar-Berman et al, 1971).

Following Schrier et al (1970), a "scan" is defined here as the occurrence of a fixation on one stimulus light followed by a fixation on the other light. The scanning behavior of the animals in the present study is summarized in Fig. 1. In few instances did either S make two or more scans on either the hard or easy series. With the exception of left-positive trials of the hard problems, the pattern of scanning seemed quite consistent, with the proportion of zero-scan and one-scan trials being about the same. For some reason, the pattern of scanning was more variable on left-positive trials of the hard problems with one animal showing a relatively high proportion of single scans and the other a high proportion of zero scans. Comparing all hard trials with all easy trials showed that Herci made one or more scans on 65% of the hard trials but on only 50% of all easy trials. However, for Tilda, these figures are 33% and 54%, respectively. Thus, the data of only one of the animals supports the finding in the preliminary work (Schrier et al, 1970) of a greater amount of scanning on the hard problems than on the easy. While the present

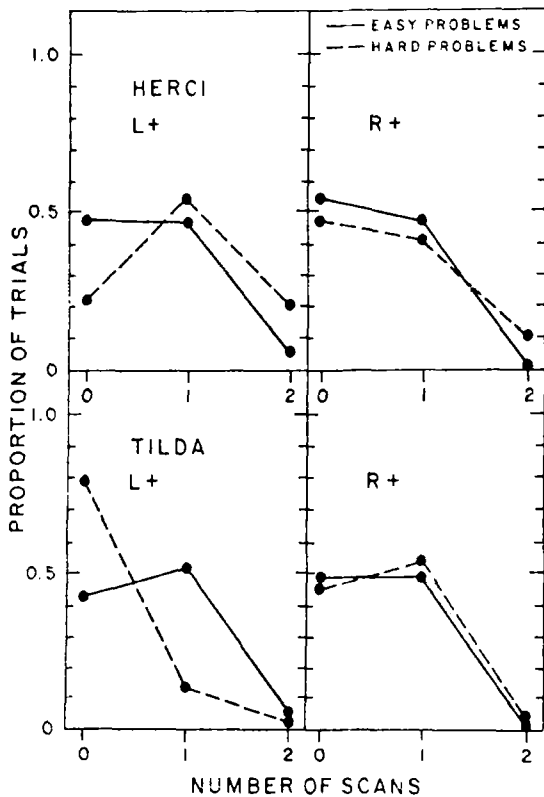


Fig. 1. Scanning behavior for trials on which the left discriminative stimulus was positive and for trials on which the right was positive and for the easy and hard problems.

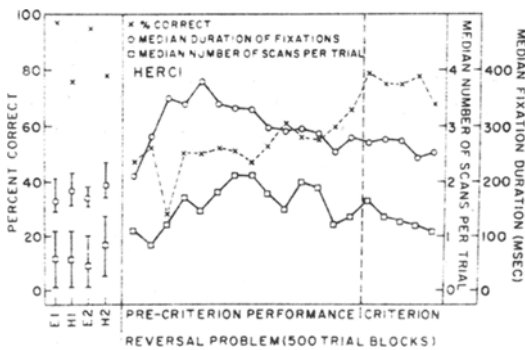


Fig. 2. Percentage of correct responses, median fixation durations, and median number of scans per trial for Herci for all problems of the experiment. The data for the reversal problem are shown in 500-trial blocks. The bars indicate the semi-interquartile ranges.

data are inconsistent on this point, subsequent work involving other types of discriminations suggests that scanning activity can be influenced by the nature of the discrimination (Schrier & Vaughan, in press).

Scanning behavior was also compared for correct and incorrect trials on the hard problems. The side of the animal's response was found to be the same as the side of the last fixation (i.e., the one overlapping the choice response) on 93% of all trials for Herci and 83% of all

trials for Tilda. These proportions did not differ for correct and incorrect trials, indicating that the animals were using a scanning pattern on incorrect trials that would have been appropriate if the negative stimulus had been positive, a finding also obtained in the earlier work (Schrier et al, 1970). Additional analyses of scanning behavior on the hard problems showed that the occurrence of one or more scans was more frequent on trials when the first fixation was of the S- than when it was of the S+. For Herci, there were one or more scans on 78% of the trials on which S- was fixated first, but on only 47% of the trials on which S+ was fixated first. For Tilda, these figures were 55% and 20%, respectively.

The data for the reversal of the hard problem are summarized in Figs. 2 and 3. These figures show that the performance of both Ss quickly reached the chance level (50% correct) and then remained at this level for over 3,000 trials. Once performance began to improve again, both animals required approximately another 3,000 trials to reach criterion. The criterion performance levels of 75% correct for Herci and 79% correct for Tilda were similar to the criterion performance levels for the prereversal hard problems.

It can be seen from Figs. 2 and 3 that the presentation of the reversal problem resulted in a rapid and relatively large increase in the average duration of individual fixations which had remained very stable for thousands of preceding trials. The change can be seen even more clearly in Fig. 4, which shows the distribution of fixation durations for the prereversal problems and that for the precriterion period of the reversal problem. The two animals displayed a similar pattern of change in fixation duration during learning of the reversal (Figs. 2 and 3). Both showed increases in median duration until a peak was reached when performance was around the chance level. As performance improved above the chance level and criterion was subsequently met, durations decreased, although never to the prereversal level. As can be seen in Fig. 2, Herci's scanning activity showed changes which paralleled those described for fixation

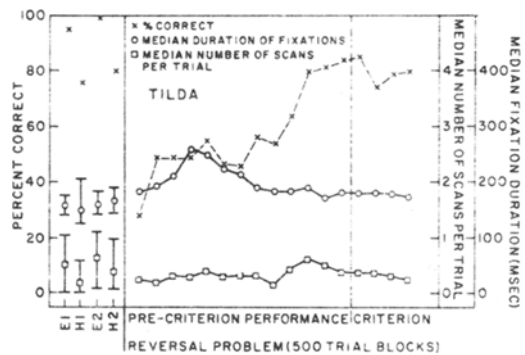


Fig. 3. Percentage of correct responses, median fixation durations, and median number of scans per trial for Tilda for all problems of the experiment. The data for the reversal problem are shown in 500-trial blocks. The bars indicate the semi-interquartile ranges.

duration. This was not the case with the other animal (Fig. 3), whose scanning behavior showed little change during the reversal problem.

An interesting development occurred during the reversal procedure in the relation of the locus of the last fixation and the choice response. As mentioned earlier, for the hard and easy series, the percentage of trials on which the choice response corresponded with the last fixation was 93% for Herci and 83% for Tilda. During the criterion performance on the reversal problem, this figure was 93% for Tilda, slightly higher than it had been before, and 34% for Herci, very low compared to what it had been earlier. As this suggests, her choice responses were more often correct when they were not on the side of the last fixation (79% correct) than when they were (67% correct). Also, Herci's performance was better when the last fixation was on S- (83% correct) than when it was on S+ (62% correct).

DISCUSSION

The average duration of individual fixations proved to be rather stable across a variety of conditions, including problem difficulty, though not inflexible, as the sharp changes following reversal clearly showed. Average duration of individual fixations ranged before reversal from 147 to 186 msec. These values are at the lower end of the range reported for humans performing a variety of visual tasks (Gould, 1969; Gould & Schaffer, 1965). However, because the type of task can influence fixation duration, more data are needed before it can be concluded that monkeys and humans are different in this respect. It should be noted that monkeys' eye movements are considerably faster than those of humans (Barmack, 1970; Fuchs, 1967).

The present type of analysis of visual behavior would seem to be valuable for examining strategies in solving problems or testing relative amounts of control exerted by positive and negative stimuli, although the present study was not specifically designed to answer questions of this type. Scanning activity was close to the average level of 0.5 scans per trial that one would expect if the animal searched efficiently for a particular one of the two discriminative stimuli on each trial. Since the position of the stimuli was randomized over trials, on half the trials the animal should find the stimulus with the first fixation (0 scans) and on the other half with the second (1 scan). Prior to reversal, the animals most frequently fixated on S+ before making a correct response, suggesting that the search was for S+. Both the tendency for minimal observing activity, at least late in training (Siegel, 1969), and the preference for observing S+ (Oscar-Berman et al, 1971) have been seen before. However, for one of the present animals, during the reversal problem, observing preference did not shift to the new S+ even after performance was at a high level. On the majority of trials, it appears that the animal fixated on the S- while responding to the opposite side.

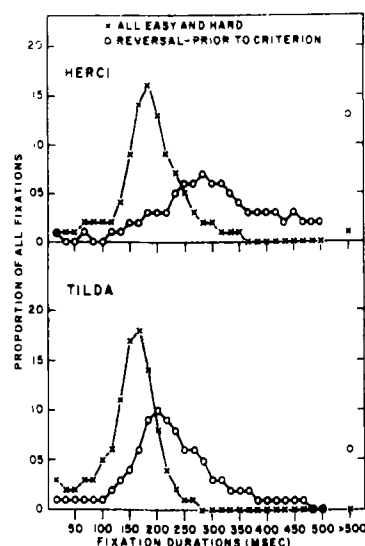


Fig. 4. Distribution of fixation durations for all problems preceding the reversal problem and for the reversal problem during the precriterion period.

As a consequence, the animal performed at a higher level on those trials when S- was fixated on last than when S+ was fixated on last. Thus, although the discriminative performance of the two animals was very similar during reversal, their observing strategies seemed to be quite different.

The reversal phase of this study provided another opportunity to test assumptions about the factors controlling observing behavior. One of the more prominent accounts of observing behavior is that of Wyckoff (1951, 1952) which emphasizes the role of secondary reinforcement in maintaining this behavior. Changes in the probability of the occurrence of observing responses mentioned in Wyckoff's theory should best be reflected, when dealing with eye movements, by measures which indicate the amount of fixating of the discriminative stimuli. For example, to satisfy a prediction of an increase in the probability of an observing response, one would expect either more scans per trial, longer durations of fixations, or both. One of Wyckoff's predictions was that the disruption of performance (e.g., by a reversal) would produce a temporary decrease in the probability of occurrence of the observing response. He also predicted that the probability of occurrence of the observing response would increase or remain high during differential reinforcement. Thus, Wyckoff would have predicted a temporary decrease in the observing response measure at the beginning of the reversal. However, the finding was that duration of fixation for both animals, and number of scans per trial for Herci, increased when the reversal problem was presented, with duration of fixation for both animals and the number of scans per trial for Herci reaching their highest levels while performance was between 45% and 55% and subsequently decreasing. Similar results have been obtained in studies in which

nonocular observing responses were used (D'Amato et al, 1968; Premack & Collier, 1966).

One could argue that these reversal results, though not consistent with Wyckoff's predictions, are nevertheless consistent with an interpretation in terms of conventional reinforcement. The increase in observing behavior following reversal could be described as temporary, and hence could have been the result of frustration resulting from a decrease in the frequency of reinforcement. In general, previous findings (D'Amato et al. 1967; Premack & Collier, 1966) do not suggest such an interpretation. In addition, other aspects of the present data do not seem to conform to predictions based on a reinforcement interpretation of observing behavior. For example, if secondary reinforcement was a factor, one would expect that S+ would be preferred over S-, and, hence, more observing behavior would be directed toward it than toward the S-. There was little evidence of this in the fixation duration data prior to reversal (Table 1) or during the early part of reversal when observing behavior was increasing. The median durations of fixation on S+ and S- during the latter period were 324 and 344 msec, respectively, for Herci and 238 and 224 msec for Tilda.

An alternative approach to the explanation of observing behavior that would appear to be more successful in accounting for at least some aspects of the present results is derived from information theory (D'Amato et al, 1968; Hendry, 1969; Lieberman, 1972). According to this view, observing responses represent an active search for information to reduce uncertainty resulting from, among other things, nonreinforcement or inconsistent reinforcement. The lack of information and resulting uncertainty could have caused the increase in observing responses that occurred following the reversal of the hard problem, with the subsequent decrease in observing responses coming as a result of decreasing uncertainty as the problem was learned.

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NOTE

1. The definition is essentially Wyckoff's (1952) as modified by Stollnitz (1965). The term has most frequently been used to refer to overt, orienting behavior. It should be recognized, however, that the definition does not specify that the behavior be observable.

(Received for publication October 30, 1972,
revision received January 15, 1973;
accepted March 2, 1973.)