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RESPONSE LATENCY AND BRIGHTNESS JUDGMENTS BY MONKEYS [1]

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Seven stumptail and four rhesus monkeys were trained on a successive black–white discrimination (e.g., black go left, white go right) and then given transfer tests to intermediate gray stimuli. Both response latencies and *S*s' judgments were recorded. Consistent with other studies and a "no vicarious trial and error" (NO-VTE) model of choice behavior, *S*s' judgments of the gray stimuli were graded rather than dichotomous. Contrary to the NO-VTE model, response latencies were curvilinearly related to the shade of gray. A simple "vicarious trial and error" (VTE) model was able to account for both main features of the data. The latter model also suggested that *S*'s initial left–right orientation was an important factor in determining whether *S*'s judgments of the gray stimuli were biased toward black or white. The response latencies of individual *S*s supported this implication.

The present experiment investigated the relationship between response latency and brightness judgments in monkeys. Davis, Masters, and Tjomsland (1965) trained humans and monkeys on a successive black–white discrimination (two black stimuli, go left—two white, go right) and then gave transfer tests to intermediate gray stimuli. Brightness judgments by humans were dichotomous; i.e., light grays were always called white and dark grays were always called black. Monkeys responded in a graded manner—the closer a gray was to black, the more likely *S*s were to judge it black. Although they did not do so for their monkeys, Davis et al. recorded response latencies for their human *S*s and found that latencies increased in a graded manner as the stimuli moved from black or white toward the middle grays. The purpose of the present study was to provide information concerning the response latencies of monkeys on this black–white scaling problem.

A model of choice behavior called the recruitment model (LaBerge, 1962) gives a good qualitative account of the Davis et al. (1965) findings and provides a specific prediction about the monkeys' response latencies. Briefly, the model suggests that for such an experiment, monkeys decide which response to make on the basis of the first bit of information gathered from the stimulus. The implication drawn from this is that monkeys' response latencies should be constant for all gray stimuli and not increase as one moves toward the middle grays. Since the recruitment model as applied here does not provide for indecision, it may be designated a "no vicarious trial and error" (NO-VTE) model. An alternative model employs the "vicarious trial and error" (VTE) concept and suggests that monkeys make decisions to respond or not respond based on information sampled from the stimulus. The VTE model predicts that response latencies will not be constant, but rather will increase as the stimuli approach the middle grays. The main difference between the two models is that the recruitment model predicts that response latency will be linearly related to the Munsell grays, while the VTE model predicts that response latency will be curvilinearly related to the Munsell grays. The structure as well as the pre-

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dictions of both models are elaborated in the Discussion section.

METHOD

Subjects.—The *S*s were seven stumptail and four rhesus monkeys. Both species were test-sophisticated and specifically had been previously trained on numerous successive problems. The stumptail monkeys were jungle-born and were approximately 5 yr. old; the rhesus monkeys were lab-born and were approximately 7 yr. old.

Apparatus.—Stimuli were matte finish Munsell papers glued to 2-in. Masonite squares. The Munsell values employed were 2 (black), 3, 4, 5, 6, 7, 8, 9, and 9.5 (white). The formboard of the Wisconsin General Test Apparatus (WGTA) was painted to match a Munsell Value 6, and the foodwells in the board were 12 in. apart center to center. To diminish surface reflectance, the formboard was slanted forward 50°. A timer to record latencies started when the opaque door of the WGTA was raised 15 in. and stopped when *S* displaced one of the stimuli.

Illumination was provided by an incandescent ceiling light and two fluorescent lights, one over the test tray, the other over the restraining cage. The surface of the test tray reflected 5.7 ftc. of light, as measured by a Macbeth illuminometer. Reflectance readings from the walls of the apparatus averaged 4.2 ftc.

Procedure.—For preliminary training, *S*s were given a black-white successive discrimination problem. If both of the foodwells were covered with black stimuli, a response to the left (or right) was correct and rewarded with a raisin; if the foodwells were covered with two white stimuli, the opposite response was correct. The alternate stimuli appeared in a balanced randomized order

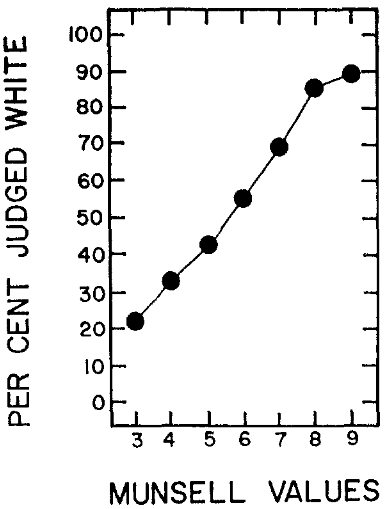

FIG. 1. Percentage of white judgments as a function of Munsell value.

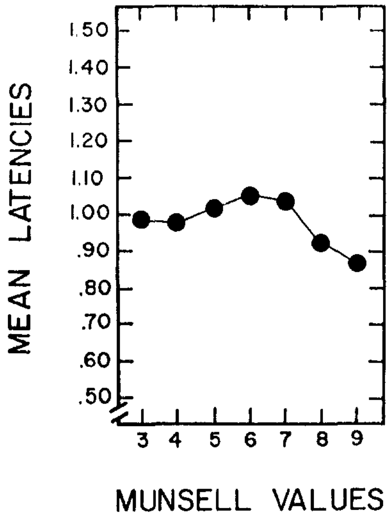

FIG. 2. Mean latency on black-white judgments as a function of Munsell value.

for 50 trials of training each day until *S* reached a criterion of 90% or better correct responses on 2 consecutive days. The intertrial interval was approximately 10 sec.

Sixteen three-trial problems were then given to each *S* daily for 14 days during transfer testing. On the first and second trials of a problem, the stimuli were either both white or both black and differential reward was still in effect. For the third trial, one of the seven pairs of gray stimuli (Values 3-9) appeared over the foodwells. Responses to either foodwell were rewarded on these trials, and *E* merely recorded which response (left or right) was made and the latency for this response. The particular gray pair appearing on third trials was randomly determined, and each pair was presented for a total of 32 trials.

RESULTS

The mean number of days to reach criterion of 90% correct responding on 2 consecutive days was 7.5. For the differentially rewarded black-white trials given during transfer testing, *S*s averaged 6.6% errors.

The *S*s' responses to the gray stimuli on the critical trials are shown in Fig. 1. The percentage of responses indicating a white judgment is plotted as a function of the Munsell values. Judgments of white increased in almost linear fashion as the value scale moved from the darkest gray to the lightest gray. The function is quite similar to that reported by Davis et al. (1965); i.e., *S*s gave graded responses to the graded grays. The mean trend is not an artifact

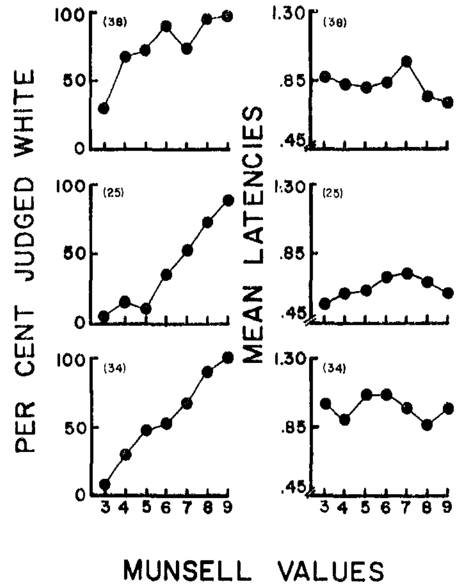

FIG. 3. Percentage of white judgments and mean latencies of black–white judgments as a function of Munsell value from an animal biased toward white (top), one biased toward black (middle), and one essentially unbiased in its judgments (bottom).

of grouping the data since individual *S*s responded in a graded manner.

The relationship of mean latency to the series of gray stimuli is shown in Fig. 2. The function is curvilinear, with mean latency reaching a maximum for the middle grays. A repeated-measures analysis of variance was performed on mean response latencies, and the effect of stimuli was found to be highly significant, $F\ (6, 60) = 4.80$, $p < .01$. A trend analysis (Winer, 1962) was then performed on the mean latencies. Both the linear component, $F\ (1, 60) = 7.06$, $p < .05$, and the quadratic component, $F\ (1, 60) = 16.20$, $p < .01$, were significant. The F ratio for trends higher than quadratic was nonsignificant.

A close look at Fig. 2 reveals that latencies in responding to the two lightest grays were shorter than latencies in responding to the two darkest grays. More *S*s were biased toward white in their judgments than toward black: five *S*s tended to be biased toward white, two seemed to be biased toward black, and the other four *S*s showed essentially no bias in their judgments. In making statements about bias, it has been assumed that the Munsell brightness scale is an equal interval scale with each step on the scale toward white yielding an equal linear increment in the proportion of white elements in the sample. If *S* made more (or less) white judgments than expected on the basis of the assumed proportion of white elements, the investigators arbitrarily said his judgments were biased toward white (or black). Figure 3 shows the judgments and latencies of *S*38, biased toward white; *S*25, biased toward black; and *S*34, essentially unbiased. The *S* with a white bias responded fastest toward the white end of the scale, the *S* with a bias toward black responded fastest toward the black end of the scale, and the unbiased *S* responded equally fast for the light and dark grays.

Discussion

The recruitment model's application to the brightness judgments and response latencies requires some elucidation. The recruitment model views a black stimulus as consisting of many black elements, a white stimulus as consisting of many white elements, and the different gray stimuli as consisting of different percentages of randomly distributed black and white elements. On a trial, *S* samples elements from the stimuli before deciding which response to make. The *S* need sample only a single element from a stimulus to perform perfectly on a black–white discrimination because only black elements can be sampled from black stimuli and white from white stimuli. The model becomes more meaningful when we ask how a stimulus consisting of a mixture of, e.g., 70% black and 30% white elements can be always judged black. If *S* samples only one element before responding, then 30% of his responses will be white judgments. The recruitment model proposes that before responding, *S* samples elements until he reaches some fixed number, *k*, of a certain type. The *S* keeps track of how many black and how many white elements he has observed and responds when his total of one type has reached *k*. Suppose *S* samples elements until he gets 20 of one kind before responding. Although there is a .30 probability that the first element sampled will be white, the probability that *S* will sample 20 white elements before sampling 20 black elements is close to zero. However, if S samples only one element before responding, he will give perfectly graded judgments to graded grays. This model suggests that the difference between the judgments of humans and monkeys is a function of how many elements are being recruited before a decision is made—monkeys sampling but a single element and humans sampling enough elements to allow their judgments to be dichotomous.

The sampling assumption translates itself directly to response latencies. Suppose that it takes time to sample each element and that S samples until he gets 20 elements of one kind. If the stimulus is light gray, it will take more samples, on the average, to reach a total of 20 white elements than if the stimulus is white because it is almost certain that some of the elements sampled from the gray stimulus will be black. If humans are recruiting a fair number of elements to make their judgments, then their response latencies should increase as one moves toward the middle grays. If monkeys are only recruiting or sampling a single element as their graded judgments suggest, then whether the stimulus is a light, middle, or dark gray, their latencies should be constant.

The prediction drawn from the recruitment model, that response latencies would be linearly related to the Munsell grays, was disconfirmed by the data. Monkeys took about 12% longer to respond to middle grays than to the light or dark grays. The following alternative model, which includes the VTE concept, accounts for the curvilinear latency gradients, the monkeys' black–white scaling, and suggests a source of individual response bias.

The model is essentially Bower's (1959) random walk model (Model B) for choice behavior, and it is conceptualized in Fig. 4. Assume S has been trained to go left to a white pair of stimuli and to go right to a black pair. When the trial begins, S first looks right with probability P and first looks left with probability $1-P$. If he looks right, he samples exactly one element from the stimulus on the right. If that element is the same color as the color to which a right response is appropriate (i.e., if the element is black, since this S has learned black—go right), he responds to that side (calls the stimulus black). This occurs with probability β, where β is the proportion of black elements in the stimulus. If he samples a white element (with probability $1-\beta$), he reorients and looks to the left. If he samples a white element here, he responds to that side (i.e., calls the stimulus white). With probability β, he will sample a black element, whereupon he reorients to the right. He again samples an element from the right stimulus and responds to the right stimulus if the element is black and orients to the left side once again if the element sampled is white. This VTE process continues until a choice is made.

Brightness judgments by Ss depend on the proportion of black and white elements in a stimulus *and* upon Ss' initial orientation. The VTE model suggests that substantial differences in judgments by different monkeys can be attributed to differences in Ss' initial orientation probabilities and not so much to different perceptions or response rules. If S first orients toward the side which white would signal him to respond to, his judgments will be biased toward white. A summation based on the model shows that one S will judge a middle gray stimulus ($\beta = .50$) to be black two-thirds of the time if he always first orients to the side appropriate to a black judgment, while another S will call this same stimulus black only one-third of the time if he always first orients to the opposite side. It is possible that the bias toward calling stimuli white in the present experiment was solely a function of initial orientation probabilities.

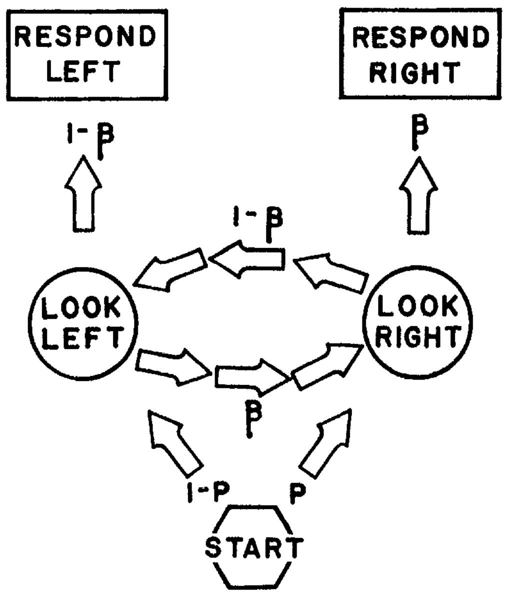

Fig. 4. Representation of the random walk (VTE) model for choice behavior. (β is the proportion of elements favoring a response to the right, while P is the initial probability of looking to the right.)

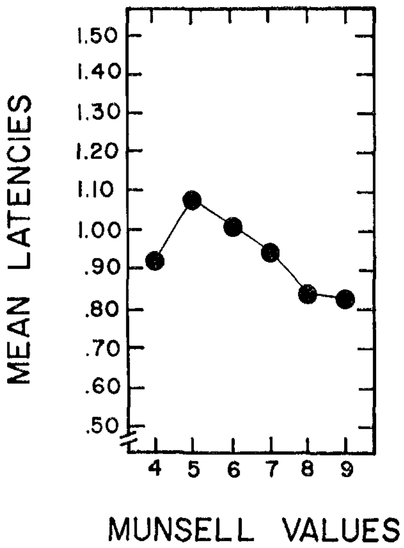

FIG. 5. Mean latency for white judgments alone for 9 of the 11 animals as a function of Munsell value.

The VTE model does not predict that the percentage of black judgments will, in general, equal the percentage of black elements in the sitmuli. If β is the percentage of black elements in the sample, then a certain proportion,

$$(\beta + \beta^2)/2(1 - \beta + \beta^2),$$

of the responses should be black judgments. If $\beta = .70$, then over 75% of the responses will be black judgments. In other words, the VTE model allows for a slight magnification of discriminability.

One additional assumption allows for a straightforward interpretation of latency data by the VTE model. We assume that each step in the VTE process depicted in Fig. 4 takes, on the average, one unit of time. Thus, if *S* looks right and then looks left and responds left, three units of time have elapsed. If *S* first orients to the side he eventually chooses, he will respond faster, on the average, than when he first orients to the side opposite his eventual choice. Since *S*s tended to be biased toward the white side, latencies should be and were somewhat shorter for the light gray stimuli. The mean latency units on judgments for a given stimulus or β value are derived by summing over predecision orienting sequences and multiplying them by their respective probabilities of occurrence. Values of β suitable to account for *S*s' judgments ($\beta =$ .80, .70, .60, .50, .40, .30, .20 for Munsell Values 3–9, respectively) were used to estimate the predicted brightness-latency function. In general, the brightness-latency function will be curvilinear, with the longest latencies occurring for the middle stimuli. More specifically, the VTE model predicts that it should take about 10% longer to respond to the middle grays than to the lightest or darkest gray, which compares well with the 12% difference found in the present experiment.

Another somewhat surprising prediction of the VTE model arises from the curvilinear latency function. According to the model, if latencies for white judgments and black judgments are plotted separately, both functions should be curvilinear. Given that *S* makes a white judgment, the shortest latencies should occur when the stimuli are either light gray *or* dark gray and the longest latencies should occur to the middle grays. Light grays will be called white much more often than dark grays, but if the dark grays are to be called white at all, this decision must be made on early orientations. In contrast, intuition suggested that if it took a certain amount of time to call a middle gray white, it should take even longer to decide that a dark gray is white. Figure 5 shows the latency function for those trials on which a white judgment was made. The darkest gray was omitted because few *S*s judged it white often enough to get stable latency estimates. Two *S*s were excluded from this function because they judged the Munsell Value 4 stimulus to be white fewer than four times. The nine other *S*s judged all of the stimuli to be white at least four times. The obtained function is curvilinear and asymmetrically displaced toward the white side, as one would expect if *S*s most often first oriented to the side appropriate to a white judgment. The *S*s took *less* time to judge the dark gray Munsell Value 4 to be white than they did to call the Munsell Value 5, 6, or 7 white. A trend analysis was performed on the latencies for white judgments, and both the linear component, F (1, 40) = 10.79, $p < .01$, and the quadratic component, F (1, 40) = 4.94, $p < .05$, were significant. This counterintuitive outcome provides substantial support for the VTE model.

In summary, the basic features of the data—the graded black–white judgments, the curvilinear latency-brightness function, differences in black–white response bias and their relationship for white judgments—are all consistent, at least on a qualitative level, with the VTE or random walk model presented here. The

VTE model suggests that monkeys use less information than humans in making their brightness judgments.

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