BEHAVIORAL STEREOTYPY AND THE GENERALIZED MATCHING EQUATION

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The development of behavioral stereotypy is a common result of exposure to both response-dependent and response-independent reinforcement procedures. The generalized matching equation and two dynamic versions of that equation, which take into account the time differential between reinforcements and their effect on behavior, predict this outcome of many procedures involving reinforcement. Following from the assumption that distinct response topographies, distinct response sequences, or orientations to distinct stimuli can be treated in the equations as distinct classes of behavior, the equations predict that—at least for matching and undermatching—the behavior class that is most biased relative to other behavior classes of the same type will tend to predominate to the exclusion or near exclusion of those behavior classes.

Key words: behavioral stereotypy, generalized matching equation, bias, response topography, behavior sequences, stimulus preferences, response preferences, response-independent reinforcement, superstitious behavior

Behavioral stereotypy is a well-established result of repeated applications of reinforcement. For example, reinforcing a particular response over a period of time reduces the variability in the force, duration, and topography of the response, even when no explicit contingency is programmed to restrict variability (e.g., Antonitis, 1951; Eckerman & Lanson, 1969; Guthrie & Horton, 1946; Notterman & Mintz, 1965; Skinner, 1938). In addition, reinforcing many different behavior sequences leads to the predominance of a small number of those sequences (e.g., Morris, 1987; Pisacreta, 1982b; Schwartz, 1980, 1982; Vogel & Annau, 1973). Moreover, reinforcement delivered on long variable-interval schedules produces repetitive sequences of behavior between responses, at least in pigeons (e.g., Pear, 1985). Furthermore, delivering reinforcement independent of behavior also generates stereotypic behavior (e.g., Skinner, 1948; Staddon & Simmelhag, 1971; Timberlake & Lucas, 1985). A final example of a reinforcement operation that results in behavioral stereotypy is the phenom-

enon of autoshaping, whereby a stereotypic response comes to be directed toward a previously neutral stimulus as a result of that stimulus being paired with a reinforcer (e.g., Brown & Jenkins, 1968; Jenkins & Moore, 1973).

It will be shown in this article that predictions of the development of behavioral stereotypy can be derived from the generalized matching equation (Baum, 1974, 1979), provided that certain assumptions are made. There are two forms of the generalized matching equation: one describes relative response rate and the other relative time allocation as a function of relative reinforcement rate. The latter form is used here because the present treatment encompasses topographically different classes of behavior, and the same response-rate scale is not generally applicable across topographically different responses. (Note, however, that the relevant derivations could be carried out for response rate with the same general conclusions as arrived at below, if an appropriate scaling factor were inserted in the equations.) The time form of the generalized matching equation can be written

$$\frac{t_i}{t_j} = b \left(\frac{r_i}{r_j} \right)^s, \tag{1}$$

where t_i and t_j are the amounts of time allocated to two independent classes of behavior, r_i and r_j are the corresponding reinforcement

rates, and b and s are nonnegative constants. The constant s, termed *sensitivity*, describes the degree to which relative time allocation is controlled by relative reinforcement rate. If sensitivity is less than one, *undermatching* is said to occur; if it is greater than one, *overmatching* is said to occur. The constant b, termed *bias*, describes the tendency to allocate more time to one alternative than would be predicted simply on the basis of relative reinforcement rate. If bias is greater than one, the behavior corresponding to t_i is biased relative to the behavior corresponding to t_j; if bias is less than one, the reverse is the case.

To derive behavioral stereotypy from the generalized matching equation, it is assumed that distinct response topographies, distinct response sequences, or orientations to distinct stimuli can be treated as distinct classes of behavior that conform to Equation 1. Thus, if t_i and t_j in Equation 1 are the times allocated to two distinct response topographies, two distinct behavior sequences, or orienting to two distinct stimuli, b represents a tendency to allocate more time to one of these behavior classes than to the other when both are reinforced equally. According to Davison and McCarthy (1988), bias describes behavior in several ways, two of which are relevant to the present treatment: (a) it describes the effects of differences between reinforcement parameters; and (b) it "can act as an individual parameter, describing a preference on the part of the subject to respond on the left alternative, or to respond on the red key, and so on" (p. 51). The latter corresponds to what Baum (1974, p. 234), in his enumeration of sources of bias, termed *response bias*. Two types of behavioral tendencies are included under this category: preferences for particular response topographies or behavior sequences and preferences for particular stimuli. Thus, a particular response topography or sequence may have a greater tendency to occur than another because of the physiology of the organism (e.g., the structure of an animal's musculature or nervous system). For example, a given topography may be "easier" to perform than another. Similarly, a particular stimulus preference may be exhibited because of the physiology of the organism. For example, an animal may show a tendency to orient toward a particular stimulus during conditions of food reinforcement, even though this orientation does not result in any advantage with regard to obtaining food.

DERIVATION OF BEHAVIORAL STEREOTYPY FROM THE GENERALIZED MATCHING EQUATION

Assume that $B = \{B_1, B_2, \ldots, B_N\}$ is the set of all behavior classes (i.e., response topographies, behavior sequences, or orientations to specific stimuli) maintained by experimentally programmed reinforcement in a given experimental space. It should be noted that B does not include behavior classes that might occur and be reinforced by nonprogrammed reinforcers (i.e., "self-reinforcing" behavior; Herrnstein, 1970, 1977a, 1977b). For example, if the reinforced response is pressing a single lever, the members of B might be the different topographies of lever pressing that can be reinforced by the programmed reinforcement. Usually a distinction is made between structural and functional definitions of behavior (Catania, 1973). Here it is assumed that although consisting of structurally similar members, the behavior classes under consideration can be defined functionally; that is, they are assumed to consist of members that vary together. The issue of distinguishing between different behavior classes of the same type (e.g., different response topographies) is therefore an empirical one. (An interesting property of the following derivations, which will not be pursued here, is that they hold even if there is overlap among the behavior classes.)

It will be assumed for now that the behavior classes under consideration are equally efficient, so that the average rate of reinforcement, R, is unaffected by which members of B occur. As a consequence of this assumption, the following treatment logically applies to response-independent as well as to response-dependent reinforcement procedures. (The effect of removing this assumption will be considered later.) Thus, the overall rate of reinforcement for any B_i is $R(t_i/T)$, where T is the total time of the experimental session. It then follows from Equation 1 that

$$\frac{t_i}{t_j} = b\left(\frac{t_i}{t_j}\right)^s, \qquad (2)$$

and hence that

$$\left(\frac{t_i}{t_j}\right)^{1-s} = b. \qquad (3)$$

If sensitivity is not equal to one, it follows from Equation 3 that

$$\frac{t_i}{t_j} = b^{\frac{1}{1-s}}. \tag{4}$$

Note that for sensitivity less than one, the proportion of time allocated to the class of behavior with the larger bias (the more biased behavior class) can be quite large relative to the amount of time allocated to the less biased behavior class. If b_1 is the bias of the behavior class with the largest time allocation relative to the behavior class with the second largest time allocation, b_2 is the bias of the behavior class with the second largest time allocation relative to the behavior class with the third largest time allocation, and so on, the time allocation of the behavior class with the largest time allocation will be larger than that of any given B_k by a factor of $(b_1^{1/1-s})(b_2^{1/1-s}) \ldots (b_k^{1/1-s})$. Thus, for sensitivity less than one, the behavior class with the largest bias relative to other behavior classes of the same type (i.e., response topographies, behavior sequences, or orientations to specific stimuli) could predominate to the near exclusion of those behavior classes. As sensitivity approaches one, exclusive preference is approached for the behavior class with the highest bias, resulting in extreme stereotypy.

In the case of sensitivity equal to one, Equation 4 cannot be used. However, Equation 3 shows that in this case exclusive preference will occur, although the equation does not specify which behavior class will be exclusively preferred. Thus, for the case of sensitivity equal to one, stereotypy will be maximal although the stereotyped behavior class need not (according to the generalized matching equation, at least) be the one with the highest bias. In the next section, modifications of the generalized matching equation will be considered that do specify that in the case of sensitivity equal to one the most biased behavior class will be the one that occurs.

If sensitivity is greater than one, the exponent in Equation 4 is negative; this implies that time allocation is inversely related to bias. This paradoxical result is a problem for the present treatment, because overmatching is not uncommonly reported in the literature. Moreover, it appears to be especially problematic because the present treatment is based on the time-allocation form of the generalized match-

ing equation, and overmatching has been reported more frequently for time allocation than for response rate. However, the conditions that give rise to overmatching and the extent to which it accurately describes behavior are still unresolved issues in the matching literature. For example, there is evidence that the use of programmed delays in the availability of reinforcement following changeovers between concurrently reinforced activities may increase sensitivity, resulting in more instances of overmatching than would otherwise occur (Baum, 1979; Myers & Myers, 1977; Scown, 1983—cited by Davison & McCarthy, 1988, p. 82; Shull & Pliskoff, 1967). Most studies on matching have used such changeover delays, which are not assumed in the present treatment. Moreover, Davison and McCarthy (1988, p. 85) have argued that the fact that the distribution of sensitivity values throughout the matching literature is skewed toward values less than one suggests that values above one are due to estimation errors. In addition, although sensitivity has often been found to be closer to one for time-allocation matching than for response-rate matching, Davison and his colleagues (Aldiss & Davison, 1985; Davison & McCarthy, 1988, p. 84; Taylor & Davison, 1983) have argued and obtained data indicating that sensitivity for time-allocation matching has been overestimated in many studies by the inclusion of pause time (i.e., time allocated to nonexperimentally reinforced activities) in the time measures. Thus, additional research is necessary before the meaning of overmatching data for the present treatment can be determined. In the next section, two modifications of the generalized matching equation are presented for which the possibility of overmatching poses a somewhat less serious problem.

MODIFICATIONS OF THE GENERALIZED MATCHING EQUATION

The generalized matching equation applies only to behavior in the stable state and does not deal with transition states. A more dynamic equation would describe how previous reinforcements result in current behavior and would specify the time intervals over which these reinforcements are integrated to produce current behavior (cf. Hineline, 1984, p. 506; Staddon, 1982, p. 255). Several dynamic models

have been proposed (e.g., Killeen, 1981; Myerson & Miezin, 1980; Staddon, 1982). Two equations are considered here which differ from these in being modifications of the generalized matching equation. The basic motivation for considering these particular equations is implied by Davison and McCarthy (1988) when they ask:

> The generalized matching law serves to specify quite accurately both the beginning and end points of transitions between concurrent schedules. Given such effective anchoring, can the performance between these end points be described using the generalized matching law extended in some way? (p. 120)

That is, the effectiveness of the generalized matching equation in describing stable-state behavior suggests that the equation might be modified to describe effectively behavior in transition as well. Moreover, a modified generalized matching equation that accurately describes behavior in transition might also describe behavior in the stable state more accurately than does the unmodified generalized matching equation.

The two equations considered here are similar to the multiplicative and additive models examined by Davison and Hunter (1979) and are therefore supported to some extent by their data and by data obtained by Hunter and Davison (1985). In presenting these equations it is assumed that animals sample relative reinforcement rates occurring in discrete intervals, called here *sampling intervals*. As considered here, unlike in Davison and Hunter's working assumptions, these sampling intervals do not necessarily represent sessions. Although both functions are discrete whereas the correct function may be continuous, discrete functions often provide reasonable approximations to continuous ones. Moreover, the rapid transitions that sometimes have been reported in studies on matching (e.g., Davison & Hunter, 1979; Hunter & Davison, 1985) as well as in simple conditioning experiments (e.g., Pear & Legris, 1987; Skinner, 1938, pp. 69–72) suggest that behavior acquisition may be a discrete process.

The Multiplicative Model

The multiplicative equation can be written

$$\frac{t_{i,n}}{t_{j,n}} = b \left(\frac{r_{i,n-1}}{r_{j,n-1}}\right)^{s_1} \left(\frac{r_{i,n-2}}{r_{j,n-2}}\right)^{s_2} \cdots \left(\frac{r_{i,n-k}}{r_{j,n-k}}\right)^{s_k}, \quad (5)$$

where $n, \ldots, n - k$ designate sampling intervals, $s_1, \ldots, s_k$ are decreasing positive numbers, and the other terms are as defined for Equation 1. The series of exponents is decreasing to represent the fact that the more recent sampling intervals would have more effect on relative time allocation than would the more remote sampling intervals (i.e., that relatively recent experiences have more effect on behavior than do earlier experiences). It is assumed that there is a finite number, k, of the exponents because of data indicating that the effect of a previous distribution of reinforcements decreases to zero as the number of sessions increases following a change in the distribution of reinforcements (Davison & Hunter, 1979; Davison & McCarthy, 1988, p. 125; Hunter & Davison, 1985). It is assumed that behavior in the nth sampling interval is not determined by the distribution of reinforcements in that interval because the principle of causality dictates that current events be caused by prior events. This assumption addresses the limitation of Davison and Hunter's (1979) multiplicative equation with respect to describing within-session changes in behavior and is consistent with the alternative theoretical function suggested by Davison and McCarthy (1988, p. 126).

The Additive Model

The additive equation can be written

$$\frac{t_{i,n}}{t_{j,n}} = b \left(\frac{w_1 r_{i,n-1} + w_2 r_{i,n-2} + \ldots + w_k r_{i,n-k}}{w_1 r_{j,n-1} + w_2 r_{j,n-2} + \ldots + w_k r_{j,n-k}}\right)^s, \quad (6)$$

where $w_1, \ldots, w_k$ are weighting factors for the reinforcement rates in the sampling intervals, $n, \ldots, n - k$, and the other terms are as defined for Equation 1. To weight more recent reinforcements more heavily than less recent reinforcements, it is assumed that the weighting factors are decreasing positive numbers. As with the multiplicative equation, and for the reasons given in connection with that equation, it is assumed that k is finite and that behavior in the nth sampling interval is not determined by the distribution of reinforcements in that interval. The following derivations show that both the multiplicative and the additive models lead to the same general predictions concerning behavioral stereotypy that are made by the generalized matching equation.

Derivations from the Models

Because the relative reinforcement rate for any behavior is equal to the overall reinforcement rate times the proportion of time allocated to that behavior, it follows from Equation 5 that for the multiplicative model

$$\frac{t_{i,n}}{t_{j,n}} = b\left(\frac{t_{i,n-1}}{t_{j,n-1}}\right)^{s_1}\left(\frac{t_{i,n-2}}{t_{j,n-2}}\right)^{s_2} \cdots \left(\frac{t_{i,n-k}}{t_{j,n-k}}\right)^{s_k}, \quad (7)$$

and from Equation 6 that for the additive model

$$\frac{t_{i,n}}{t_{j,n}} = b\left(\frac{w_1 t_{i,n-1} + w_2 t_{i,n-2} + \ldots + w_k t_{i,n-k}}{w_1 t_{j,n-1} + w_2 t_{j,n-2} + \ldots + w_k t_{j,n-k}}\right)^s. \quad (8)$$

Assume that the models describe behavior at or approaching a stable state; that is, assume that for all n, either

$$\frac{t_{i,n}}{t_{j,n}} \geq \frac{t_{i,n-1}}{t_{j,n-1}} \quad (9a)$$

or

$$\frac{t_{i,n}}{t_{j,n}} < \frac{t_{i,n-1}}{t_{j,n-1}}. \quad (9b)$$

The arbitrary assignment of the numerators and denominators in Equations 5 and 6, and consequently in Equations 7 and 8, means that the reciprocals of the two sides of Inequality 9b satisfy Inequality 9a. Therefore, we need only consider Inequality 9a in deriving the steady state predicted by each model. It follows from Inequality 9a and Equation 7 for the multiplicative model, and from Inequality 9a and Equation 8 for the additive model, that

$$b\left(\frac{t_{i,n-1}}{t_{j,n-1}}\right)^s \geq \frac{t_{i,n}}{t_{j,n}} \geq b\left(\frac{t_{i,n-k}}{t_{j,n-k}}\right)^s, \quad (10)$$

where $s = s_1 + s_2 + \ldots + s_k$ in the multiplicative model.

From the left side of Inequality 10 we obtain

$$\frac{t_{i,n}}{t_{j,n}} \leq b\left(\frac{t_{i,n-1}}{t_{j,n-1}}\right)^s$$

$$\leq b^{s+1}\left(\frac{t_{i,n-2}}{t_{j,n-2}}\right)^{s^2} \leq \ldots$$

$$\leq b^{(s^{n-k-1}+s^{n-k-2}+\ldots+s+1)}\left(\frac{t_{i,k}}{t_{j,k}}\right)^{s^{n-k}}, \quad (11a)$$

and from the right side of Inequality 10 we obtain

$$\frac{t_{i,n}}{t_{j,n}} \geq b\left(\frac{t_{i,n-k}}{t_{j,n-k}}\right)^s \geq b^{s+1}\left(\frac{t_{i,n-2k}}{t_{j,n-2k}}\right)^{s^2} \geq \ldots$$

$$\geq b^{\left(s^{\frac{n-1}{k}-1}+s^{\frac{n-1}{k}-2}+\ldots+s+1\right)}\left(\frac{t_{i,1}}{t_{j,1}}\right)^{s^{\frac{n-1}{k}}}. \quad (11b)$$

It follows from Inequalities 11a and 11b that for sensitivity not equal to one,

$$b^{\frac{1-s^{n-k}}{1-s}}\left(\frac{t_{i,k}}{t_{j,k}}\right)^{s^{n-k}} \geq \frac{t_{i,n}}{t_{j,n}} \geq b^{\frac{1-s^{\frac{n-1}{k}}}{1-s}}\left(\frac{t_{i,1}}{t_{j,1}}\right)^{s^{\frac{n-1}{k}}}. \quad (12)$$

If sensitivity is less than one, the limiting form of Inequality 12 as n grows increasingly large is

$$b^{\frac{1}{1-s}} \geq \frac{t_{i,n}}{t_{j,n}} \geq b^{\frac{1}{1-s}},$$

and it therefore follows that for n approaching infinity

$$\frac{t_{i,n}}{t_{j,n}} = b^{\frac{1}{1-s}}. \quad (13)$$

Because Equation 13 is essentially the same as Equation 4, it follows that for the case of undermatching the multiplicative and additive models both make the same quantitative prediction for the stable state that is made by the generalized matching equation. That is, both models imply that behavioral stereotypy will develop during response-dependent and response-independent reinforcement.

If sensitivity is equal to one, it can be seen from Inequality 11b that both the multiplicative and the additive models predict that as n grows increasingly large exclusive preference will be approached for the alternative with the larger bias. Again, this is essentially the same as the prediction made by the generalized matching equation for the case in which sensitivity is equal to one. However, the generalized matching equation does not specify the alternative toward which exclusive preference will be directed, whereas the prediction made by the two modified models is both specific and reasonable.

If sensitivity is greater than one, examination of Inequalities 11a and 11b reveals that relative time allocation is predicted by the multiplicative and additive models to be a direct

joint function of both bias and the initial relative time allocation, because the contribution of each of these factors increases exponentially as n increases. This differs from the generalized matching equation, which predicts an inverse relation between bias and relative time allocation in the stable state and no effect of initial relative time allocation on behavior in the stable state. Clearly, a direct relationship between relative time allocation and bias is more reasonable than an inverse one. In addition, the prediction of an exponentially increasing relationship between initial and final relative time allocation implies that arbitrary behavior that initially happens to occur by "chance" (i.e., as a result of unspecified variables) could increase over time to become predominant. Consequently, the idiosyncratic stereotypic behavior reported by Skinner (1948), which he described as "superstitious," could conceivably be accounted for by overmatching. Thus, knowledge of the conditions that produce overmatching might help to explain inconsistencies in the literature concerning the effects of response-independent reinforcement (Skinner, 1948; Staddon & Simmelhag, 1971; Timberlake & Lucas, 1985).

DISCUSSION

It was shown in the previous section that two plausible dynamic modifications of the generalized matching equation give rise to predictions with regard to behavioral stereotypy that are similar or identical to those of the generalized matching equation. All three models predict that, at least in the cases of matching and undermatching, stereotypy will occur in the direction of the most biased reinforced behavior class in a given experimental situation. Overmatching is problematic for the present treatment, especially with respect to the unmodified generalized matching equation. However, as indicated earlier in this article, most studies report undermatching, and the extent to which reported cases of overmatching may be artifactual or caused by sampling error has not been resolved (Davison & McCarthy, 1988, p. 85).

Two sources of bias relevant to the present treatment were mentioned in the introduction—response bias and differences between reinforcement parameters. With regard to response bias, response topographies that re-

quire less effort than others would be expected to be biased relative to topographies that require more effort. For example, rats that begin pressing a lever in various ways for food typically show "an increasing tendency to use an economical paw movement to press the lever" (Millenson & Leslie, 1979, p. 35). Also included in the category of response bias are tendencies to respond more to some stimuli than to others. For example, Pisacreta (1982a) found that pigeons develop a dominant pattern of matching-to-sample behavior when given a choice of stimuli to match, with each bird in the study appearing to have its own stimulus-preference hierarchy. An example of a difference between reinforcement parameters in the present context would be response topographies that are not equally efficient in procuring reinforcers. It can be shown that multiplying relative reinforcement rate by a factor of c has the effect of multiplying bias by a factor of c^c in all three models discussed in this article. Differences between other reinforcement parameters such as amount or delay of reinforcement would have a similar effect if, as proposed by Baum and Rachlin (1969), these parameters are incorporated as factors in the matching formulation.

Response biases and differences between reinforcement parameters would be expected from the present treatment to interact in a multiplicative fashion. There is some evidence that this is the case. Using a computer system that tracked pigeons' responding in an operant chamber, Pear (1985) found that stereotypic behavior sequences developed between key pecks reinforced by food on variable-interval schedules. The dominant pattern depended on the value of the schedule. The birds usually remained close to the key and pecked during a short variable-interval schedule, but engaged in stereotypic movements away from the key during a long variable-interval schedule. Consideration of the various feedback functions that have been suggested for variable-interval schedules (Nevin & Baum, 1980) indicates that reinforcement rate is reduced proportionately more on short than on long variable-interval schedules by behavior resulting in long interresponse times. Pear's finding is consistent with the present treatment if it is assumed that pigeons have a bias toward movements such as looping or circling in the presence of stimuli paired with food reinforcement, but that this

bias is effectively overridden by the disproportionately large decrease in reinforcement rate it causes on short variable-interval schedules. It should be noted that this bias is not attributable to any strong self-reinforcing property of looping, circling, pacing, and so on, because pigeons rarely engage in these stereotypic activities under baseline conditions in which no food is available.

Timberlake and Lucas (1985) reported data with a fixed-time 15-s schedule indicating an interaction between reinforcement parameters and response bias. They conducted a series of experiments that showed that pigeons exposed to response-independent food presentations tend to engage in locomotor behavior away from the feeder immediately after food presentations and in feeder-wall-directed activity prior to food presentations. In one experiment (Experiment 2) a specific response that had been shaped decreased sharply in favor of stereotypic feeder-wall-directed activity when the birds were exposed to response-independent food presentations. A similar result was obtained by Eldridge, Pear, Torgrud, and Evers (in press). Although the behavior that had been shaped in that study (a locomotor response) persisted above its baseline level after the return to response-independent reinforcement, it occurred immediately after reinforcement and feeder-wall-directed behavior occurred toward the end of the 15-s interreinforcement interval so that the birds were close to the food source when the feeder operated. Thus, the bias toward a particular behavior class may vary as a function of the temporal proximity of reinforcement.

In another experiment by Timberlake and Lucas (1985, Experiment 5) feeder-wall-directed behavior was replaced by another stereotypic activity when the former behavior caused reinforcement to be omitted. It appears that the pigeons in Timberlake and Lucas' study and in Eldridge et al.'s (in press) study had strong response biases toward locomotor activity and orienting toward a wall in situations involving intermittent food presentations. The fact that it was usually the feeder wall toward which they directed their activity near the end of the interreinforcement interval was probably due to the greater efficiency of this behavior in procuring reinforcers. When contingencies were introduced that rendered this behavior ineffective, its bias apparently decreased relative to that of the other behavior, which therefore replaced it.

Findings regarding autoshaping also seem to be consistent with the present treatment. For example, the fact that pigeons' autoshaped key pecks are redirected to a region near the key when key pecks cause scheduled food presentations to be omitted (Barrera, 1974; Eldridge & Pear, 1987) may be the result of an interaction between a relatively high bias to orient toward and peck at stimuli paired with food and the relatively low reinforcement rate for that behavior. Unlike the Pavlovian account of autoshaping, the present interpretation has no difficulty with the fact that, although highly stereotypic, an autoshaped response need not resemble the response elicited by the reinforcer (Timberlake & Grant, 1975; Wasserman, 1973).

A possible limitation of the extensions of the generalized matching equation discussed here should be noted. Studies by Page and Neuringer (1985) and by Neuringer (1986) showing that response variability can be increased by reinforcement contingent on variability are not readily accommodated by the present treatment. However, Morris (1987) has found that this result occurred only with a discrete-trials procedure in which each response was followed by a brief timeout. Thus, the present treatment may apply only to data obtained under free-operant procedures. Alternatively, interruptions of key pecking by a timeout after each key peck in procedures designed to reinforce variability may facilitate the formation and reinforcement of complex behavior sequences between key pecks, producing increased variability in key-pecking patterns.

Although speculative, the treatment presented in this paper appears to be testable. For example, one test would be to evaluate the bias for a particular stereotypic activity developed under response-independent reinforcement relative to a more arbitrary activity. This assessment could be done by placing the two activities on concurrent variable-interval variable-interval schedules. If the present account is correct, bias should be greater for the activity that developed under response-independent reinforcement. In addition, the relative weightings of activities with regard to bias should correspond directly to their order of emergence under response-independent reinforcement when reinforcement omission contingencies are

applied to the more dominant activities. The means necessary for detecting and recording specific topographies in such experiments may be provided by future developments in tracking and shaping systems (e.g., Eldridge & Pear, 1987; Pear & Legris, 1987).

REFERENCES

Aldiss, M., & Davison, M. (1985). Sensitivity of time allocation to concurrent-schedule reinforcement. *Journal of the Experimental Analysis of Behavior,* **44,** 79–88.

Antonitis, J. J. (1951). Response variability in the white rat during conditioning, extinction, and reconditioning. *Journal of Experimental Psychology,* **42,** 273–281.

Barrera, F. J. (1974). Centrifugal selection of signal-directed pecking. *Journal of the Experimental Analysis of Behavior,* **22,** 341–355.

Baum, W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior,* **22,** 231–242.

Baum, W. M. (1979). Matching, undermatching, and overmatching in studies of choice. *Journal of the Experimental Analysis of Behavior,* **32,** 269–281.

Baum, W. M., & Rachlin, H. C. (1969). Choice as time allocation. *Journal of the Experimental Analysis of Behavior,* **12,** 861–874.

Brown, P. L., & Jenkins, H. M. (1968). Auto-shaping of the pigeon's key-peck. *Journal of the Experimental Analysis of Behavior,* **11,** 1–8.

Catania, A. C. (1973). The concept of the operant in the analysis of behavior. *Behaviorism,* **1**(2), 103–116.

Davison, M. C., & Hunter, I. W. (1979). Concurrent schedules: Undermatching and control by previous experimental conditions. *Journal of the Experimental Analysis of Behavior,* **32,** 233–244.

Davison, M., & McCarthy, D. (1988). *The matching law: A research review.* Hillsdale, NJ: Erlbaum.

Eckerman, D. A., & Lanson, R. N. (1969). Variability of response location for pigeons responding under continuous reinforcement, intermittent reinforcement, and extinction. *Journal of the Experimental Analysis of Behavior,* **12,** 73–80.

Eldridge, G. D., & Pear, J. J. (1987). Topographical variations in behavior during autoshaping, auto-maintenance, and omission training. *Journal of the Experimental Analysis of Behavior,* **47,** 319–333.

Eldridge, G. D., Pear, J. J., Torgrud, L. J., & Evers, B. H. (in press). Effects of prior response-contingent reinforcement on superstitious behavior. *Animal Learning & Behavior.*

Guthrie, E. R., & Horton, G. P. (1946). *Cats in a puzzle box.* New York: Rinehart.

Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior,* **13,** 243–266.

Herrnstein, R. J. (1977a). Doing what comes naturally: A reply to Professor Skinner. *American Psychologist,* **32,** 1013–1016.

Herrnstein, R. J. (1977b). The evolution of behaviorism. *American Psychologist,* **32,** 593–603.

Hineline, P. N. (1984). Aversive control: A separate domain? *Journal of the Experimental Analysis of Behavior,* **42,** 495–509.

Hunter, I., & Davison, M. (1985). Determination of a

behavioral transfer function: White-noise analysis of session-to-session response-ratio dynamics on concurrent VI VI schedules. *Journal of the Experimental Analysis of Behavior,* **43,** 43–59.

Jenkins, H. M., & Moore, B. R. (1973). The form of the auto-shaped response with food or water reinforcers. *Journal of the Experimental Analysis of Behavior,* **20,** 163–181.

Killeen, P. R. (1981). Averaging theory. In C. M. Bradshaw, E. Szabadi, & C. F. Lowe (Eds.), *Quantification of steady-state operant behaviour* (pp. 21–34). Amsterdam: Elsevier/North-Holland Biomedical Press.

Millenson, J. R., & Leslie, J. C. (1979). *Principles of behavioral analysis* (2nd ed.). New York: Macmillan.

Morris, C. J. (1987). The operant conditioning of response variability: Free-operant versus discrete-response procedures. *Journal of the Experimental Analysis of Behavior,* **47,** 273–277.

Myers, D. L., & Myers, L. E. (1977). Undermatching: A reappraisal of performance on concurrent variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* **27,** 203–214.

Myerson, J., & Miezin, F. M. (1980). The kinetics of choice: An operant systems analysis. *Psychological Review,* **87,** 160–174.

Neuringer, A. (1986). Can people behave "randomly?": The role of feedback. *Journal of Experimental Psychology: General,* **115,** 62–75.

Nevin, J. A., & Baum, W. M. (1980). Feedback functions for variable-interval reinforcement. *Journal of the Experimental Analysis of Behavior,* **34,** 207–217.

Notterman, J. M., & Mintz, D. E. (1965). *Dynamics of response.* New York: Wiley.

Page, S., & Neuringer, A. (1985). Variability is an operant. *Journal of Experimental Psychology: Animal Behavior Processes,* **11,** 429–452.

Pear, J. J. (1985). Spatiotemporal patterns of behavior produced by variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* **44,** 217–231.

Pear, J. J., & Legris, J. A. (1987). Shaping by automated tracking of an arbitrary operant response. *Journal of the Experimental Analysis of Behavior,* **47,** 241–247.

Pisacreta, R. (1982a). Preferences among stimulus matches in the pigeon. *Journal of the Experimental Analysis of Behavior,* **38,** 191–199.

Pisacreta, R. (1982b). Some factors that influence the acquisition of complex, stereotyped, response sequences in pigeons. *Journal of the Experimental Analysis of Behavior,* **37,** 359–369.

Schwartz, B. (1980). Development of complex, stereotyped behavior in pigeons. *Journal of the Experimental Analysis of Behavior,* **33,** 153–166.

Schwartz, B. (1982). Interval and ratio reinforcement of a complex sequential operant in pigeons. *Journal of the Experimental Analysis of Behavior,* **37,** 349–357.

Scown, J. M. (1983). *Changeover delay and concurrent schedules.* Unpublished doctoral dissertation, Waikato University, New Zealand.

Shull, R. L., & Pliskoff, S. S. (1967). Changeover delay and concurrent schedules: Some effects on relative performance measures. *Journal of the Experimental Analysis of Behavior,* **10,** 517–527.

Skinner, B. F. (1938). *The behavior of organisms: An experimental analysis.* New York: Appleton-Century.

Skinner, B. F. (1948). "Superstition" in the pigeon. *Journal of Experimental Psychology, 38,* 168–172.

Staddon, J. E. R. (1982). Behavioral competition, contrast and matching. In M. L. Commons, R. J. Herrnstein, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol. 2. Matching and maximizing accounts* (pp. 243–261). Cambridge, MA: Ballinger.

Staddon, J. E. R., & Simmelhag, V. L. (1971). The "superstition" experiment: A reexamination of its implications for the principles of adaptive behavior. *Psychological Review, 78,* 3–43.

Taylor, R., & Davison, M. (1983). Sensitivity to reinforcement in concurrent arithmetic and exponential schedules. *Journal of the Experimental Analysis of Behavior, 39,* 191–198.

Timberlake, W., & Grant, D. L. (1975). Auto-shaping in rats to the presentation of another rat predicting food. *Science, 190,* 690–692.

Timberlake, W., & Lucas, G. A. (1985). The basis of superstitious behavior: Chance contingency, stimulus substitution, or appetitive behavior? *Journal of the Experimental Analysis of Behavior, 44,* 279–299.

Vogel, R., & Annau, Z. (1973). An operant discrimination task allowing variability of reinforced response patterning. *Journal of the Experimental Analysis of Behavior, 20,* 1–6.

Wasserman, E. A. (1973). Pavlovian conditioning with heat reinforcement produces stimulus-directed pecking in chicks. *Science, 181,* 875–877.