Reinforced Variability in Animals and People

Implications for Adaptive Action

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Although reinforcement often leads to repetitive, even stereotyped responding, that is not a necessary outcome. When it depends on variations, reinforcement results in responding that is diverse, novel, indeed unpredictable, with distributions sometimes approaching those of a random process. This article reviews evidence for the powerful and precise control by reinforcement over behavioral variability, evidence obtained from human and animal-model studies, and implications of such control. For example, reinforcement of variability facilitates learning of complex new responses, aids problem solving, and may contribute to creativity. Depression and autism are characterized by abnormally repetitive behaviors, but individuals afflicted with such psychopathologies can learn to vary their behaviors when reinforced for so doing. And reinforced variability may help to solve a basic puzzle concerning the nature of voluntary action.

Most people can repeat a behavior when asked to do so or vary it on demand. They hide a coin in a fixed pattern—left hand, right hand, left hand—so that a child can easily find it, or they make prediction difficult by varying the pattern. Research shows that repeating and varying are, in part, learned skills under the control of reinforcing consequences. This may surprise those who believe that reinforcement always leads to repetition, that it constrains and narrows thought and behavior and therefore that reinforcement is detrimental—something to be avoided—because it interferes with creativity, originality, and individuality. Research demonstrates otherwise: Animals and people learn to increase or decrease variability; they respond stereotypically or stochastically, depending on which of these best confronts a problem or attains a goal. Variability does not necessarily fade as knowledge is gained but rather it is maintained at highest levels when that is functional. An understanding of functional variability—technically referred to as *operant variability*—may help psychologists to train new behaviors, treat psychopathologies, and explain some deeply puzzling phenomena, including how voluntary responses differ from reflexes. To introduce the research on this topic, I describe a debate initiated in ancient times but continuing until today.

Variability Implies Ignorance

Most psychologists assume that behavior is determined—caused, controlled, generated—by a combination of influences based on genes, conditioning and developmental experiences, and current stimuli. "Determinism reigns," wrote the historian of psychology E. G. Boring (as quoted in Gigerenzer, 1987, p. 13). One reason for this determinist assumption is that it motivates persistence in the search for lawful relationships, persistence despite current ignorance; another is that the history of psychological science shows that as knowledge is gained, behaviors become increasingly predictable and, at least in some cases, controllable.

Roots of this determinist position are found in early Greek writings. "Nothing occurs by chance, but there is a reason and necessity for everything," said Leucippus (as quoted in Jammer, 1973, p. 587), and Democritus surmised that the physical world is composed of indivisible atoms, the movements of which are determined. These early philosophers were attempting to replace a belief in chance with the predictability of natural law, a task taken up in different fashion by Christian theologians. Both St. Augustine and St. Aquinas maintained that chance was a name for man's ignorance and not a true attribute of the world. God created a determined universe.

Descartes' reflex, Newton's laws, the British Associationists' philosophies—all embodied determinist assumptions. Consider Laplace (restating Leibnitz):

An intelligent being who, at a given instant, knew all the forces animating nature and the relative position of the beings within it, would, if his intelligence were sufficiently capacious to understand these data, include in a single formula the movements of the largest bodies of the universe and those of its slightest atoms. Nothing would be uncertain to him; the future as the past would be present to his eyes. (Laplace, 1814; as quoted in Dennett, 2003, p. 28)

These views anticipated Einstein's contention that God does not play dice with the universe.
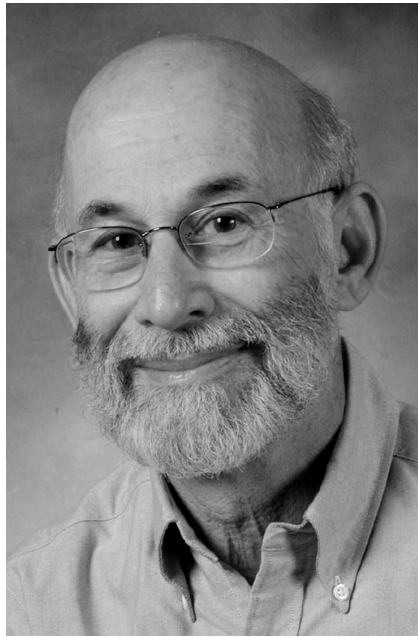
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From La Mettrie and Helmholtz through Freud and Gestaltists to behaviorists, most psychologists shared the view that variability is a sign of ignorance, and therefore experimental procedures were designed to minimize variability so as to discover underlying causes. In recent times, the determinist position has been associated most closely with B. F. Skinner, a radical behaviorist, who wrote, "We cannot prove . . . that human behavior . . . is fully determined, but the proposition becomes more plausible as facts accumulate" (Skinner, 1974, p. 189). Behaviorists do not stand alone in this regard, for determinist assumptions are common in many other areas of contemporary psychology, including cognitive, social, developmental, physiological, clinical, and personality.

Variability Is Functional

According to a competing claim, however, some things cannot be predicted, even if complete knowledge is assumed: chance-like, random, or stochastic effects do not disappear. Those who hold to this *indeterminist* position argue that variability is more than a sign of ignorance—it is real—and attempting to characterize a population by statistical summaries such as mean or median will only obscure the true underlying diversity.

Epicurus agreed with Democritus that the motion of atoms are often determined, but in order to explain novelty, creativity, and voluntary action, he posited that atoms occasionally swerved randomly—a proposal that has resonated through the ages:

The swerve envisioned by Epicurus is not due either to an external force or to a change in the atom itself but is entirely uncaused. It is not just that [we] cannot discover the cause. . . . There is simply no cause to be discovered. (Cahn, 1967, p. 74)

While Descartes and the British Associationists were providing mechanical interpretations of action, Pascal and Fermat conceptualized the universe as a gaming table and formulated probability theory. When Newtonian physics was at its heights, Charles Peirce's theory of tychism hypothesized chance as the basis of all physical and psychological phenomena, and as will be seen, his friend, William James, adopted that philosophy. Random variations play an essential role in the theory of evolution, with variations arising not only from externally induced mutations but also from processes endogenous to the cell, such as random assortment of chromosomes and jumping genes. These latter examples suggest that genetic variability is maintained actively. In contemporary physics, randomness is the basis for quantum mechanics.

Psychology has had its share of indeterminist theorizing as well. James wrote that events

have a certain amount of loose play . . . so that . . . one of them does not necessarily determine what the others shall be. . . . [Indeterminism] admits that possibilities may be in excess of actualities, and that things not yet revealed to our knowledge may really in themselves be ambiguous. Of two alternative futures . . . both may now be really possible; and the one becomes impossible only at the very moment when the other excludes it by becoming real itself. Indeterminism thus denies the world to be one unbending . . . fact. It says there is a . . . pluralism in it. (James, 1884/ 1956, pp. 150–151)

These views anticipate *superposition* in contemporary physics, the theory that a subatomic particle exists in many different potential states and places, with the actual occurrence emerging randomly (McFadden, 2000). Regarding voluntary behavior, James (1884/1956) wrote in the same paper, "Indeterminate future volitions *do* mean chance" (p. 158), implying that voluntary actions are, to some extent, random in nature.

Gustav Fechner, an influential progenitor of contemporary psychophysics, developed the indeterminist position. Psychological phenomena were "collectives" of instances, with general laws describing the averages but chance governing the instances. Thus, scientific laws describe classes, or sets, within which chance or probability reigns. Fechner referred to *Unbestimmtheit*, meaning indeterminacy, and *Zufall*, meaning chance, and argued that "the world has some amount of objectively existing '*Indetermination*' . . ., which 'really depends . . . on freedom,' as Fechner puts it, and which is not just the result 'of our ignorance of the conditions'" (Heidelberger, 1987, p. 123). Indeterminate events are a real part of the real world and not due simply to faulty knowledge.

Skinner is often mistakenly characterized only as a determinist, but in fact he held views similar to Fechner's. Both Fechner and Skinner were determinists regarding general laws, but both argued that individual instances often could not be predicted. Skinner distinguished between two types of conditioned responses, Pavlovian (also referred to as *respondent*) and operant (also referred to as *instrumental*). Knowledge concerning previous experiences with conditioned and unconditioned stimuli would permit precise predictions of Pavlovian reflexes. Operants

were different, however, for they could be predicted only at the level of "class." Similar to Fechner, Skinner argued that each operant instance was a member of a generic class and that whereas the class was functionally related to environmental events, the instances emerged stochastically. Skinner (1935/1959, p. 351) wrote

Suppose that we are studying the behavior of . . . a rat in pressing a lever. The number of distinguishable acts on the part of the rat which will give the required movement of the lever is indefinite and very large. . . . They constitute a class, which is . . . defined by the phrase "pressing the lever." Now it may be shown that . . . the rate of (lever-press) responding . . . maintains itself or changes in lawful ways. But the responses which contribute to this total number-per-unit-time are not identical. They are selected at random from the whole class—that is, by circumstances which are independent of the conditions determining the rate. (See also Malone, 1987; Moxley, 1997)

Skinner's emphasis on response rates (as opposed to stimulus–response probabilities or latencies) was based on his view of the operant as an emissive, rather than stimulus-determined, phenomenon (Skinner, 1950).

Epicurus, James, Fechner, and Skinner provided the background for contemporary research on the operant nature of behavioral variability. In the sections to follow, I review the evidence, discuss possible explanations, and indicate some functions and implications.

Operant Variability

Before considering the research, it will be helpful to define, in general terms, some key concepts. *Operant responses* are controlled by reinforcers and discriminative stimuli. For example, pigeons peck a response key (the operant) to obtain mixed grain (the reinforcer) when an overhead light is green (the discriminative cue). To demonstrate that response variability is an operant, one must show that it is influenced by reinforcers and discriminative stimuli. *Variability* often connotes high variability, but the term is also used to indicate a continuum, from repetition to random. In either case, variability implies the existence of a set or class of possible responses, and its measurement requires specification of the set. *Random* (or highest variability) implies that although relative frequencies (or probabilities) of members of a set can be predicted, individual instances cannot, even assuming complete knowledge. *Random* and *stochastic* are used interchangeably. The precise definition of *random* is debated, and many different statistical tests are used to assess it, no one of which suffices to demonstrate randomness (Knuth, 1969; Nickerson, 2002). However, behavioral studies often use the U value statistic to summarize the relative equality of response frequencies, which is one indication of stochastic generation, with U approaching 1.0 when frequencies are approximately equal and approaching 0.0 when one possibility predominates. In other words, the U value provides an index of the relative entropy (or uncertainty) of a set of outcomes (see Wasserman, Young, & Cook, 2004, this issue). I turn next to the experimental evidence for operant control over response variability.

Figure 1
Evidence for Stochastic Responding by Pigeons
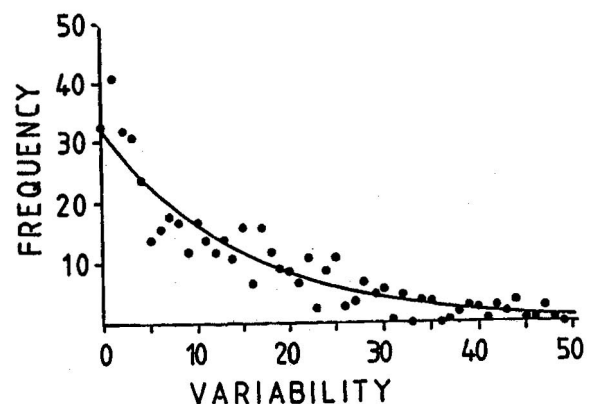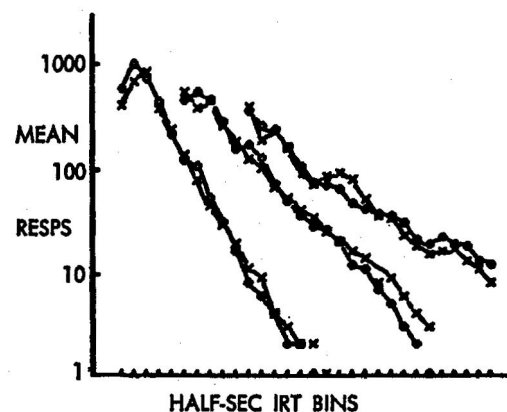
Note. The top graph shows data from one pigeon in Blough (1966) under different parameter conditions (the three sets of lines), with replication at each parameter. Shown are the mean numbers of responses (RESPS) emitted in each half-second (HALF-SEC) interresponse time (IRT) bin, with a straight line expected from a stochastic responder. From "The Reinforcement of Least Frequent Interresponse Times," by D. S. Blough, 1966, *Journal of the Experimental Analysis of Behavior, 9,* p. 587. Copyright 1966 by the Society for Experimental Analysis of Behavior. Adapted with permission.

The bottom graph shows data from one pigeon at the end of training in Machado (1989). The line represents the expected frequencies from a random model. From "Operant Conditioning of Behavioral Variability Using a Percentile Reinforcement Schedule," by A. Machado, 1989, *Journal of the Experimental Analysis of Behavior, 52,* p. 161. Copyrighted 1989 by the Society for Experimental Analysis of Behavior. Reprinted with permission.

Interresponse Time Variability

Blough (1966) performed the first and most influential experiment in this area: Pigeons were reinforced for pecking a response key randomly in time, much like an atomic emitter. Normally, animals and people show fixed and predictable response patterns, but when reinforced for varying, responses came to approximate the random model, shown by the approximately straight line distributions in Figure 1 (top graph). Blough's research stimulated many

studies that confirmed and extended his findings, but before turning to these, I will describe—and explain—an often-cited failure to reinforce variability (Schwartz, 1980, 1982).

Response Sequence Variability

Schwartz (1982) attempted to reward pigeons for varying sequences of left (L) and right (R) pecks across two response keys. If the current sequence (or pattern) of eight responses differed from the immediately preceding pattern (e.g., as in LLLLRRRR differing from RRRRLLLL), food was given, but even after extended training, the birds only rarely succeeded at this task. Schwartz (1982) suggested that the failure to vary was due to an unfortunate consequence of reinforcement: Namely, it causes responses to become repetitive and stereotyped. But in fact, the failure was an unintended effect of one aspect of Schwartz's (1982) procedure—that exactly four L and four R responses were required to occur in each trial. When Page and Neuringer (1985) reinforced pigeons for varying but without the four L plus four R constraint, the birds varied impressively. For example, when reinforcement depended on the pattern in the current trial differing from as many as each of the previous 50 patterns (a Lag 50 variability [var] contingency), the pigeons learned to approximate a random model, reminiscent of Blough's (1966) findings. That reinforcers were directly controlling response variability was shown by a yoke control condition under which the pigeons had to peck eight times to complete a trial and were reinforced at exactly the same frequency as in var, but variability was no longer required. Under this yoke condition, variability decreased significantly, with the easiest sequences such as LLLLLLLL and RRRRRRRR tending to predominate (see also Barba & Hunziker, 2002; Machado, 1992). Thus, a dependent relationship between reinforcers and response variations was necessary for the high levels of variability observed.

A computer simulation of the Schwartz (1982) procedure offered additional evidence for the importance of the behavior–reinforcer relationship. The simulation showed that a random responder was reinforced only infrequently under Schwartz's (1982) procedure, this because, by chance, the simulator often responded more than four times on one or the other key (Page & Neuringer, 1985). When the four L plus four R was removed, the random simulator was reinforced frequently. Thus, stochastic responding under Schwartz's (1982) contingencies was not often reinforced—and the pigeons did not vary—whereas under Page and Neuringer (1985), stochastic responding was successful—and responding varied greatly. I will return below to evidence suggesting that animals and people in fact are capable of responding stochastically and that such responding is controlled by reinforcement, possibilities that have important theoretical implications. But first I describe additional ways in which reinforcement controls variability.

Response Topography Variability

Pryor, Haag, and O'Reilly (1969) extended Blough's (1966) study to different types of behaviors and a different species. Whereas Blough and Page and Neuringer (1985) defined specific sets of instances in order to reinforce variability—16 interresponse intervals in one case and 256 response sequences in the other—Pryor et al. reinforced porpoises for generating novel behaviors—flips, turns, jumps, and so on—ones that had not previously been observed within the context of the experiment. The title of their article, "The Creative Porpoise: Training for Novel Behavior," describes their results: The subjects behaved in ways that had never before been observed in any porpoise. Applying similar techniques to preschool children, Goetz and Baer (1973) successfully reinforced novel block constructions and drawings.

Random Number Generation

In many studies over the past 60 years, human participants have been asked to respond randomly (e.g., randomly call out "heads" and "tails," or the digits zero through nine, or randomly press eight buttons), the results being that, in almost every case, response distributions were easily distinguished from random (Brugger, 1997; Nickerson, 2002). With only one exception, participants in these studies received neither feedback nor reinforcement for approximating a random distribution—they were simply instructed to respond randomly. In one study, however, feedback was provided, and the results differed markedly (Neuringer, 1986). In this latter case, students were asked to enter *1* and *0* randomly on a computer keyboard. For the first 6,000 responses (the experiment lasted for many sessions), no feedback was provided, and the results were as previously reported, with responses easily distinguished from random. A shaping procedure was then applied in which a participant first received feedback from one statistical test, and when participant and random model were statistically indistinguishable, from two tests, and so on until 10 different statistical evaluations of response randomness were provided. The results were clear: Participants' performances became statistically indistinguishable from random according to these and some (but not all) other statistical tests. Three statistical distributions generated by a representative participant are shown in Figure 2. The left graphs show the distributions in the preliminary phase, before feedback was provided, and the right at the end of training. In each case, the dashed line represents the random model. Thus, once again, reinforcement of variations produced highly variable, and in this case approximately random, responding.

Precise Control by Reinforcement

That response variability can be reinforced—sometimes to highest levels—was shown by the above research, but how precise is such control? That is, can reinforcement contingencies produce particular levels of variability, from repetitive to random-like? Machado (1989) provided evidence for precision when he systematically manipulated both reinforcement contingencies (which specified a minimum level of variability necessary for reinforcement) and reinforcement frequencies (which specified the frequency of reinforcement for varying). The general issue was whether variability is controlled in a way similar to other operant

Figure 2
Performance by One Human Participant at the Beginning (Left Graphs) and End (Right Graphs) of Training to Respond Stochastically
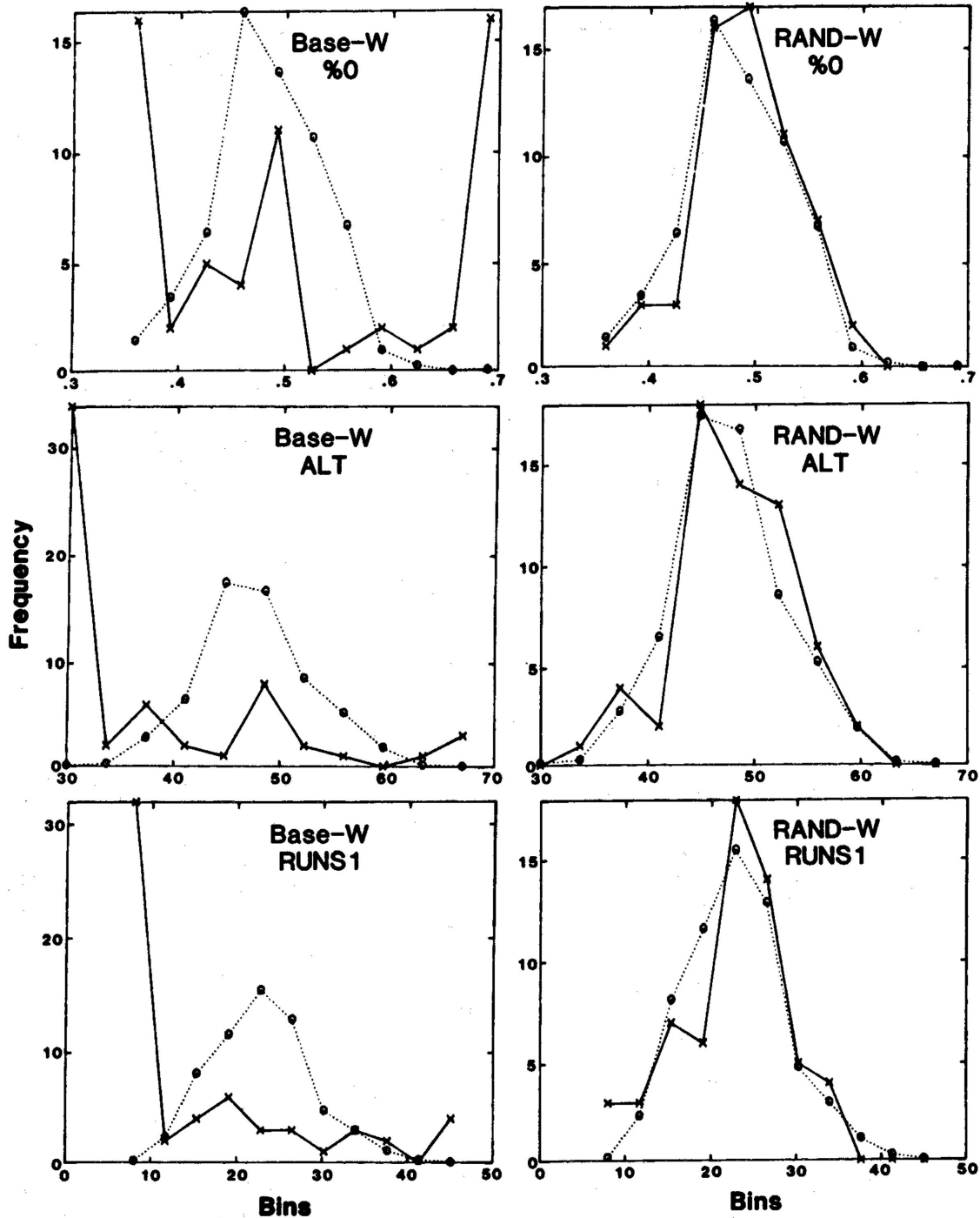

Note. Shown are comparisons on three different statistics between the participant (solid lines and *x*s) and the random model (dashed lines and open circles). (The random model's functions appear different in left and right graphs because of the different scales along the *y*-axis used to best show the participant's performances.) At the end of training, the participant did not differ statistically from the random model on these or on seven additional statistics. *Base-W* and *RAND-W* refer to performances for Participant W under pretraining baseline conditions and end-of-training test conditions, respectively. %0 = percentage of zero (vs. one) responses per trial; ALT = number of times per session that zero was followed by one or vice versa; RUNS1 = number of times per session that a single one was followed by one or more zeros, or a single zero was followed by one or more ones. From "Can People Behave 'Randomly'? The Role of Feedback," by A. Neuringer, 1986, *Journal of Experimental Psychology: General, 115,* p. 70. Copyright 1986 by the American Psychological Association. Reprinted with permission.

dimensions, such as response speed and force. Machado (1989) found that, just like these other dimensions, variability was precisely controlled by the reinforcement contingencies and, as is often found in the other cases, reinforcement frequencies exerted relatively little control. That is, Machado's (1989) pigeons generated the levels of variability that were required by the contingencies, but the overall frequencies of reinforcement had almost no influence (see also Blough, 1966; Jensen, Miller, & Neuringer, in press). Although some previous studies have indicated that infrequent reinforcement tends to increase variability, the effects are small and inconsistent (see Balsam, Deich, Ohyama, & Stokes, 1998; Grunow & Neuringer, 2002; Neuringer, Kornell, & Olufs, 2001). Thus, it is more important what one reinforces than how frequently, a conclusion that applies to operant variability as it does to many other response dimensions.

Reinforcement contingencies control levels of variability, as just described, but more than that, reinforcement specifies which aspects of a response must vary and which must repeat. For example, Ross and Neuringer (2002) asked college students to draw rectangles, one at a time, on a computer screen, using the computer's mouse. Online analyses were performed on three response dimensions: size (or area) of the rectangles, form (height divided by width), and location on the screen. For each of these dimensions, 16 categories were established, and, without informing the participants, one group was reinforced for repeatedly drawing rectangles of a particular size while simultaneously varying screen location and form. A second group was required to repeat location but to vary size and form, and the third group was required to repeat form and vary location and size. Therefore, in each case, points were provided contingent on the participant simultaneously repeating along one dimension and varying along the other two. The results were that the three groups differed significantly, each responding appropriately (i.e., one group varied size and shape while repeating form, etc.). These results were all the more interesting because most participants could not identify the reasons for their successes (i.e., why some drawn rectangles were reinforced and others not) and because simple binary feedback (points awarded or not) sufficed to control levels of variability along three orthogonal response dimensions. Reinforcement powerfully and precisely controls which aspects of a response will repeat, which will vary, and how much.

Reinforcement also controls the extent to which one chooses to vary. An extensive literature shows that when animals choose between alternatives, for example, pressing L or R levers, choice probabilities match relative frequencies of reinforcement. If a subject is reinforced twice as often for going L than R, it tends to choose L twice as often as R. I asked whether pigeons' choices to vary or repeat would similarly match relative reinforcement frequencies (Neuringer, 1992). A sequence of four responses was defined as a *var* sequence if it differed from each of the previous four patterns (Lag 4) and defined as *rep* if it repeated any one of the previous four. Frequencies of reinforcement for var and rep sequences were systemati-

Figure 3
Levels of Response Variability (Shown by U Value)
When Discriminative Stimuli (VARY and YOKE) Were
Present Versus Absent
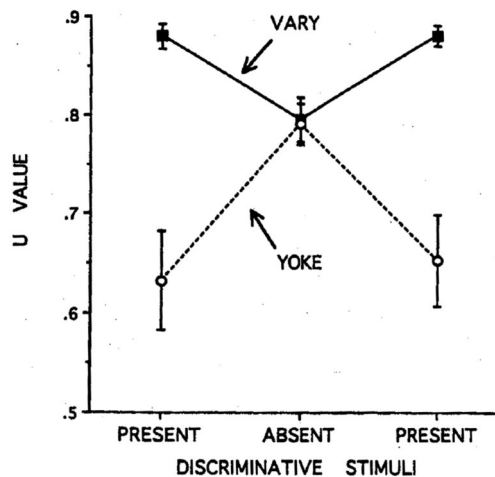
Note. Error bars show standard deviations. VARY = reinforcement depended on emission of variable response sequences; YOKE = reinforcement was provided independently of response-sequence variability. From "Behavioral Variability Is Controlled by Discriminative Stimuli," by J. Denney and A. Neuringer, 1998, *Animal Learning & Behavior, 26,* p. 159. Copyright 1998 by the Psychonomic Society. Reprinted with permission.

cally manipulated, and the main finding was a matching-like function: As frequency of reinforcement increased for varying, responses increasingly varied; and, similarly, repetitions were most common when they were differentially reinforced. Thus, choosing to vary or repeat is controlled in the same manner as other kinds of choices.

Control by Discriminative Stimuli

Stimuli indicate what, when, and where a response is likely to be reinforced, and control by such discriminative cues is another defining characteristic of operant responses. To test whether variability is similarly controlled, Page and Neuringer (1985) rewarded pigeons for repeating a single response sequence across two keys (LRRLL) when keylights were blue but required sequence variations when keylights were red. Appropriately repetitive and variable responding resulted, each controlled by its color cue. The precision of stimulus control was seen in a similar experiment by Denney and Neuringer (1998), in this case with rats. The rats responded variably across two levers when that was cued (var condition) and more repetitively under yoke stimuli when variability was not required. (Reinforcement in the yoke phase was as frequent as in var but based simply on completing a trial rather than on variability.) Figure 3 shows that levels of variability differed significantly (vary vs. yoke) when discriminative cues were provided (left-hand and right-hand points) but did not differ when, in a control phase, the cues were removed (middle points). These studies indicate that discriminative cues

control response variability, as do reinforcement contingencies, and thus variability appears to be similar to other commonly studied operants. Examples include a rat pressing a lever in the presence of one tone but not another, a child approaching a cookie jar, and an adult pulling the arm of a slot machine—all examples of operant responses partly under the influence of reinforcement contingencies and discriminative stimuli. Note that each of these responses also has the appearance of being under the voluntary control of animal or person: The rat is not forced to press the lever, nor the child to reach for cookies, nor (at least in most cases) the adult to gamble. I will return to a discussion of the voluntary nature of operant variability, but first I consider explanations. What are some possible sources of operant variations?

Sources of Operant Variability

Behavioral variability sometimes results when reinforcement is withheld, as indicated above (Savage, 2001), as well as from physiological injury and drugs (Brugger, 1997), but such variability appears to be of a different type than that under discussion; it is elicited or reflexive in nature, and, although it might contribute, elicited variation will not account for the reinforcement effects described above—the yoke control procedures show that. Three additional explanations of operant variability will be discussed in this section.

Random Environmental Events

A coin tossed at the beginning of a football game indicates which team is to kick the ball. Random events such as this have been used for thousands of years: for divination, decision making, and games of chance (Jay, 2003). Random number tables and computer-based random generators are used to assign subjects to experimental conditions. In *The Dice Man,* a novel by Rhinehart (1998), a psychiatrist finds himself bored with life, and he devises a way to reinvigorate himself: He writes on slips of paper a variety of possible actions, some commonplace, some unusual, some dangerous, and when so moved, randomly selects one and acts accordingly. More generally, external random events are often used as an instrument to create unpredictable outcomes, direct choices, and influence lives.

Memory for Prior Responses

Memory for past behaviors can serve as a way to avoid repetitions. For example, when rats are placed in a maze containing eight arms radiating out as spokes, with a food pellet at the end of each arm, the rats readily learn to enter each arm once and not to repeat (because repetitions are never reinforced), with performances, to large extent, based on memory for location (Cook, Brown, & Riley, 1985). Similarly, some teachers call on students in a classroom without repeating, thereby assuring equal opportunity to speak. One could, indeed, memorize a list of random numbers, with behaviors mapped onto the list.

Chaos theory describes another memory-based system that can result in variable behavior. As evidence, one study reinforced college students for emitting chaotic-like sequences (Neuringer & Voss, 1993). Participants entered digits on a keyboard, with feedback showing how closely their responses approximated iteration of a chaotic function. Responses came increasingly to approximate the function and therefore to be quite noisy in terms of the sequence of values. However, as required by chaos theory, each successive response was related to preceding response(s) (see Metzger, 1994; Ward & West, 1994). The important point is that chaotic processes may provide the basis for highly variable responding, with current responses controlled by memory (explicit or implicit) for preceding events.

Endogenous Stochastic Generation

The third source of operant variability is controversial. A stochastic (or random) process implies, as James (1884/1956) indicated more than a century ago, that a particular response cannot be predicted from knowledge of any prior event (i.e., a knowledgeable observer can do no better than to predict the relative frequency, or probability, of the response). For example, if choices between L and R button presses were governed by an equiprobable stochastic process, then approximately equal numbers of L and R responses could be predicted, but the next response (or responses) could not be anticipated. Stochastic does not imply that a person does (or can do) anything, because, as indicated above, there must always be reference to a set, or class, of possible responses. In the example just given, the class is composed of L and R responses, but the class can be much larger and, in some cases, can include all responses currently available. Nor does stochastic necessarily imply equal probabilities. For example, one can use the toss of a die to decide whether to respond L or R but choose L only when 1 appears and R given any of the other five possible outcomes. The evidence to be reviewed supports a stochastic-generating process as a third source of operant variability. Although it is impossible to prove stochasticity—that is like proving the null hypothesis—evidence consistent with the hypothesis is of two forms, correlational and experimental, as will now be described.

Correlational evidence comes from cases in which reinforced variability is compared with that expected from a random process, such as Blough's (1966) reinforcement of random-like interresponse times in pigeons (Figure 1, top graph) and Neuringer's (1986) study with human random number generation (Figure 2), both described above. In Machado's (1989) study, also described above, the results were again those expected from a random source (Figure 1, bottom graph). Machado (1992) wrote of a related experiment: "Results suggest that . . . subjects behave as if they were flipping a coin before each response and acting accordingly" (p. 249).

There are at least two problems with relying solely on such correlational evidence, however. First, any sequence is a member of an infinite random series. For example, although if someone tosses an unbiased coin, 100 "heads" in a row is exceedingly unlikely, that sequence will be observed in an infinite series. Second, as just discussed,

Figure 4
Levels of Response Variability (Shown by Percentage of Reinforced Trials) as Number of Responses Per Trial Increased
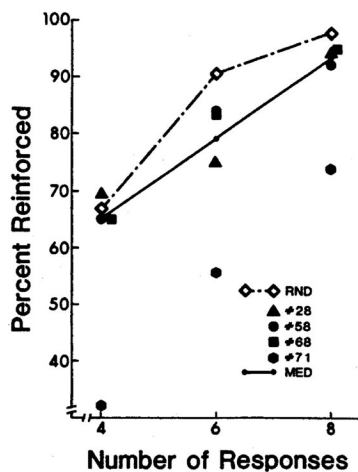
Note. Individual pigeons' data are shown by the filled symbols, with the average (MED) shown by the solid line. The broken line shows data from a simulating random generator (RND) responding under identical contingencies. From "Variability Is an Operant," by S. Page and A. Neuringer, 1985, *Journal of Experimental Psychology: Animal Behavior Processes, 11*, p. 440. Copyright 1985 by the American Psychological Association. Reprinted with permission.

there are memory-based and determinate ways to generate random-like outcomes. Indeed, any case of apparently stochastic generation can possibly be explained by memory (e.g., for a long list of random numbers or by chaotic processes). However, *experimental evidence* also supports the contributions of stochastic processes to operant variability, and this will now be described.

That memory cannot explain all instances of operant variability was suggested by the Lag 50 contingencies in the Page and Neuringer (1985) study described above: It is unlikely that pigeons can remember each of their last 50 sequences. The same article reported another more direct test. Under a Lag 3 contingency—reinforcement depended on responses in the current trial differing from each of the previous three sequences—the number of responses per trial was systematically manipulated: four, six, and eight responses per trial in the three phases, with the Lag 3 maintained throughout. The results, shown in Figure 4, were that as responses per trial increased, the pigeons were increasingly likely to satisfy the contingencies and therefore increasingly likely to be reinforced. That is, pigeons performed better when each trial consisted of eight responses than when each had only four. The same graph also shows the success rate of a simulating random model that responded with probabilities of 0.5 L and 0.5 R under four, six, and eight responses per trial conditions. The similarity between pigeons' responses and the random model is informative, as will next be explained.

As responses per trial increased, the random model was reinforced increasingly because of the laws of chance:

Repetitions are less likely by chance, given large samples than small. For example, if two tosses of a coin constituted a trial, then the probability that the current trial repeats the just-previous one is 0.25 (because there are four possible patterns, heads–heads, heads–tails, tails–heads, and tails–tails). On the other hand, if each trial consisted of eight tosses, the probability of a repetition is 1/256, or 0.004. Thus, if the pigeons were responding stochastically, then their probability of being reinforced would increase as responses per trial increased and that is exactly what happened. Although technical issues are involved, when additional experiments were performed, the results were consistent with a stochastic-generator hypothesis (i.e., that the birds were responding like the random model and not basing current responses on memory for previous sequences; Jensen et al., in press).

Another experiment compared memory and stochastic hypotheses by imposing pauses between responses in order to interfere with memory (Neuringer, 1991). The baseline schedule was one in which pigeons were reinforced if the current sequence of four responses differed from those in each of the previous five trials (var, Lag 5). The experimental manipulation involved imposing a time-out period (keys dark and inactive) after every response, these time-outs increasing from 0 to 20 seconds across phases of the experiment. As time-outs increased, the pigeons were forced to pause for increasingly long periods between each response. The question was the following: How would that affect the birds' ability to vary? The answer is shown in Figure 5 (left graph): Over the shortest time-outs, performances improved (i.e., the pigeons responded increasingly variably as responding slowed). Over the longer time-out durations, variability remained at a high level. A similar effect is found when human subjects attempt to generate random numbers (i.e., variability increases with pause duration; Baddeley, 1966).

How would memory and stochastic-generator hypotheses explain these results? I reinforced another group of pigeons (rep) for generating a single fixed pattern of responses, namely, LLRR. The same time-outs were imposed as for the var group, and Figure 5 (right graph) shows that the rep function was opposite to that from var. At the shorter time-out intervals, rep performances were excellent, but as time-out durations continued to increase, performances were severely degraded. If one assumes that successfully repeating the LLRR sequence depends on memory for the previous response(s) in the sequence, then the data suggest that pigeons remembered over approximately a six-second window but not beyond. Therefore, when pauses were longer than six seconds, memory-based performance was degraded. Because performance by var pigeons was excellent at the longest pause durations, their variable responding cannot be explained by a memory-based process.

Why, however, did var performances improve over the shorter time-out durations? Weiss (1964) hypothesized that memory for past responses might actually interfere with ability to generate random responses. This, together with a tendency for pigeons to emit "double pecks," or to

Figure 5

Response Variability as Responding Was Slowed for Two Groups of Rats: One Group Was Reinforced for Varying and the Other for Repeating
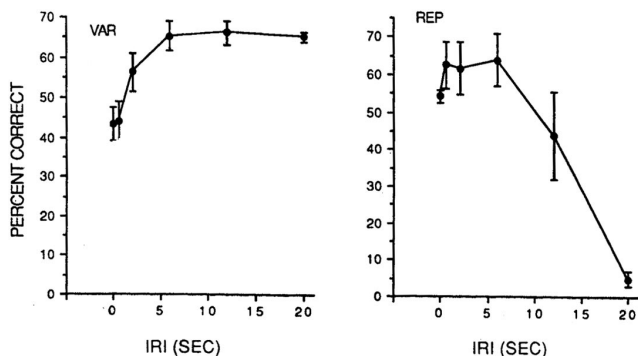
Note. The left graph shows percentages of trials in which rats satisfied a variability contingency (VAR) as a function of the interresponse times (IRI) imposed by time-outs following each of the initial three responses in a four-response trial. (The last response in the trial immediately led to food when the contingency was satisfied.) The right graph shows percentages of trials that rats repeated a single required sequence (REP), left–left–right–right, again as a function of IRI. Lines connect the arithmetic means of five VAR and six REP rats, with error bars showing standard errors. From "Operant Variability and Repetition as Functions of Interresponse Time," by A. Neuringer, 1991, *Journal of Experimental Psychology: Animal Behavior Processes, 17*, p. 7. Copyright 1991 by the American Psychological Association. Reprinted with permission.

respond repetitively on the same key (Blough, 1966; Morris, 1987), would account for the improvement by var animals across the short intervals. In any case, the fact that variability remained high as pauses lengthened to 20 seconds is consistent with a stochastic-generator hypothesis, one that assumes no role for memory in the stochastic process.

A related procedure was used in another attempt to interfere with memory. McElroy and Neuringer (1990) administered alcohol to two groups of rats, rep and var, with the same results as those just described: Alcohol severely degraded repetitive LLRR performances but had no influence on operant variability (see also Cohen, Neuringer, & Rhodes, 1990; Doughty & Lattal, 2001).

The evidence is therefore consistent with an endogenous stochastic-type generating process as one source for operantly variable behavior. Qualities of this stochastic generator include the following: training results in its output approximating a random process (Neuringer, 1986); it can generate different levels of variability (Blough, 1966; Grunow & Neuringer, 2002; Jensen et al., in press; Machado, 1989); animals can choose to engage it or not (Neuringer, 1992); it can be applied to particular sets of responses (Mook, Jeffrey, & Neuringer, 1993) or to response dimensions (Ross & Neuringer, 2002); and, it can be turned on or off, depending on cues in the environment (Denney & Neuringer, 1998). These attributes taken together suggest that stochastic responding is an operant, controlled by its consequences, and therefore functional.

Additional functions of variability will be discussed in the next section.

Functions of Variability

Variability has been found to be functional in many scientific domains. For example, in physics, adding noise to a system can increase the likelihood of distinguishing a signal from its absence, a phenomenon known as stochastic resonance; similar effects are found in biology (Moss & Wiesenfeld, 1995). Responding in an unpredictable, noisy manner is a tactic often taken when animals are confronted by a potential predator (Driver & Humphries, 1988). Variability can serve attractive functions as well (e.g., variable vocalizations by male song birds attract females; Catchpole & Slater, 1995). In psychology, variable and rich environments facilitate brain development, yielding increased numbers of neurons and synaptic connections (Renner & Rosenzweig, 1987); and variable and unexpected consequences may be necessary for conditioning Pavlovian responses (Rescorla & Wagner, 1972). Operant variability shares this heritage of functionality but does so in some unique ways as well.

Operant Learning

Shaping (or training) of a new operant response often depends on baseline variability. For example, before his owner can reinforce Fido the dog for fetching a ball, Fido must approach the ball and perhaps accidentally touch it, as he bounds around the yard. That is, before a given response can be reinforced, it must occur for other reasons, generally as an instance of a set of varying responses. Baseline variability is always present to some extent. But, in addition, the same reinforcers that selectively strengthen individual responses or sequences can also generate the requisite variability. These dual functions of reinforcement—variability generating and instance strengthening—can be successfully used by behavioral therapists, trainers, and modelers, as indicated by the following experiment.

Pigeons were initially reinforced for varying four-response sequences across two keys under a Lag 5 contingency (Neuringer, 1993). After the pigeons had learned to vary, 2 of the 16 possible sequences were selected for special treatment (e.g., LRRR and RLLL), with one of these always reinforced (regardless of whether its emission had satisfied the Lag 5 variability contingency) and the other never reinforced (again, independently of whether it met the variability contingency). Variability continued to be reinforced among the remaining 14 sequences. Thus, one sequence was always reinforced, another never, and 14 reinforced for varying, these contingencies being simultaneously in place. The frequencies of the always and never target sequences quickly diverged, with the always sequence rising significantly above its initial baseline levels (when it was part of the varying set) and above the frequencies of all other sequences and the never sequence falling significantly. On reversal of always and never contingencies, the individual sequences changed appropriately. The decrease in the never sequence was due, of course, to

the fact that it was never reinforced; the increase in always was presumably due to the fact that it was reinforced more frequently than any other response or strategy. This experiment established that exactly the same reinforcers that maintain high variability can concurrently selectively reinforce (or not) individual instances.

Knowledge concerning this dual reinforcement function may be especially helpful when training complex responses. For example, Neuringer, Deiss, and Olson (2000) compared three procedures used to train a difficult-to-learn sequence in rats, namely, RLLRL. Throughout the experiment, whenever the target RLLRL sequence occurred, it was immediately reinforced with a food pellet. In addition, one group of rats (var) was occasionally reinforced for sequence variability (same pellet reinforcers presented on the average of once per minute for satisfying the var contingencies). We reasoned that the additional reinforcers for variation might produce the baseline variability necessary for reinforcement to strengthen the target sequence, as just discussed. A yoked-control group (yoke) received concurrent reinforcement on the same VI one-minute schedule but independently of levels of variation, this condition controlling for the motivational effects of the added reinforcers. A target-only control group received no reinforcers other than for emitting the target sequence, this condition indicating the inherent difficulty of learning the RLLRL sequence. The top portion of Figure 6 shows that the target-only group extinguished or stopped responding (because the difficult target sequence was only rarely emitted and therefore the animals were rarely reinforced), whereas the var and yoke animals continued to respond at high rates throughout the experiment—the additional reinforcers serving to motivate responding in both of these groups. Of most importance, only the var animals learned the difficult target (bottom of Figure 6). The yoke and target-only groups learned little or not at all, showing that concurrent reinforcement of variability facilitated acquisition of a complex behavior.

Variations are functional in many other situations, for example, variations in training facilitate acquisition of motor skills (Manoel & Connolly, 1997; Schmidt & Lee, 1999), and variability of strategy use is correlated with acquisition of cognitive competencies such as mathematics skills (Siegler, 1996). Explicit reinforcement-of-variability procedures might be usefully applied in these domains as well, but to date there is little research on this conjecture.

Problem Solving

Reinforcement of variability may also be functional when attempting to train an animal or person to solve problems (e.g., Lung & Dominowski, 1985). Arnesen (2000) used a rat model to ask whether a history of explicit reinforcement of variations would facilitate later problem solving. Rats in an experimental group were first reinforced for varying their interactions with arbitrarily selected objects. For example, a soup can was placed in the chamber and the rat reinforced for responding to it in various ways, with an emphasis on novel responses, similar to the Pryor et al. (1969) and Goetz and Baer (1973) procedures described

Figure 6
Reinforcement of Variations Facilitates Acquisition of a Difficult Response Sequence
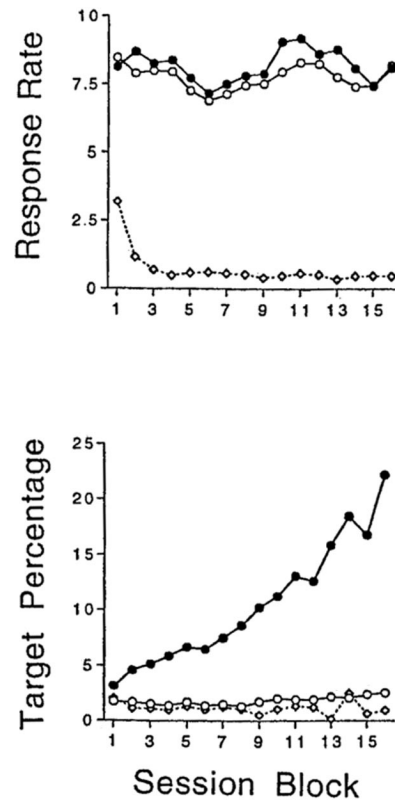
Note. The top graph shows average rates of responding (trials per minute) by each of three groups of rats across blocks of six sessions per point. The bottom graph shows the percentage of trials in which the target sequence, right–left–left–right–left, was emitted. The variability contingency group is represented by filled circles and a solid line, the yoke group by open circles and a solid line, and the target-only group by open circles and a dashed line. From "Reinforced Variability and Operant Learning," by A. Neuringer, C. Deiss, and G. Olson, 2000, *Journal of Experimental Psychology: Animal Behavior Processes, 26,* pp. 102–103. Copyright 2000 by the American Psychological Association. Reprinted with permission.

above. A different object was used during each session and the rats were required to vary their interactions throughout. Members of one control group, yoke, experienced identical training objects but were reinforced independently of their interactions. A second control group was simply handled. Following their training experiences, each rat was placed alone in a problem space, a room approximately 6 feet × 8 feet, on the floor of which were 30 objects—for example, a toy truck, metal plumbing pipes, a hair brush, a doll's chest of drawers—arbitrarily chosen but different from those used during the preliminary training phase. Hidden within each object was a small piece of food, and the hungry rats were permitted to explore freely for 20 minutes. The question was simple: How many food pellets would be discovered and consumed? The experimental animals found significantly more pellets than either of the

control groups, which did not differ from one another. Furthermore, the experimental rats explored more—they seemed bolder—and interacted more with the objects than did the controls, many of whom showed signs of fear. Thus, prior reinforcement of response variations transferred to a novel environment and facilitated exploration of novel objects and discovery of reinforcers. The advantages incurred by variations is hinted at in the human literature (e.g., "brainstorming"), but again there have been few tests of direct reinforcement-of-variability procedures for problem solving more generally.

Creativity

Researchers who study creativity debate whether reinforcement facilitates or interferes with it. Donald Campbell (1960) maintained that random variations are essential to produce creative works. To the extent that Campbell is correct, reinforcement of variability may play a constructive role. Supporting evidence includes the studies described above in which novel responses by children were reinforced (Goetz & Baer, 1973) as well as a series of experiments by Eisenberger (e.g., Eisenberger & Selbst, 1994). But, a body of literature indicates the opposite: namely, that reinforcement interferes with creativity (e.g., Amabile, 1996). The two sides of the debate are associated with different areas of psychology, behavioral researchers reporting positive effects of reinforcement but developmental and social psychologists the opposite. Research on operant variability may help to clarify the issue, as shown by the following experiment.

A common finding in the behavioral literature is that when reinforcement becomes available after a fixed number of responses or elapse of a fixed period of time, animals and people respond with increasing energy and speed as the reinforcement is approached. Accuracy increases as well (e.g., when learning to discriminate between stimuli or match one stimulus to another; Nelson, 1978; Nevin, 1967). It is as if the closer the reinforcer, the more vigorous and accurate is performance. Cherot, Jones, and Neuringer (1996) asked whether the same pattern would hold for variability: Would it too increase as a reinforcer—that was contingent on variations—was approached? The question is related to such real-world cases as when a composer is rushing to complete a composition before the scheduled performance or a student is trying to write a creative poem to meet the teacher's deadline.

Pigeons served as subjects, and variability of four-response sequences across L and R keys was reinforced (var group). However, this study differed from those described above in that the pigeons had to satisfy the variability contingency four times to gain a single reinforcement. This is a fixed-ratio four schedule of reinforcement that is superimposed on a variability response requirement. In essence, the birds had to vary three times without reinforcement in order to get a food pellet for their fourth variation. The question was whether variability would increase as the pigeons proceeded through the fixed ratio. A second group of birds, the controls, experienced a condition in which repetitions were required for reinforcement under

Figure 7

Operant Variations Decrease and Operant Repetitions Increase as Reinforcement Is Approached Under a Fixed-Ratio Schedule
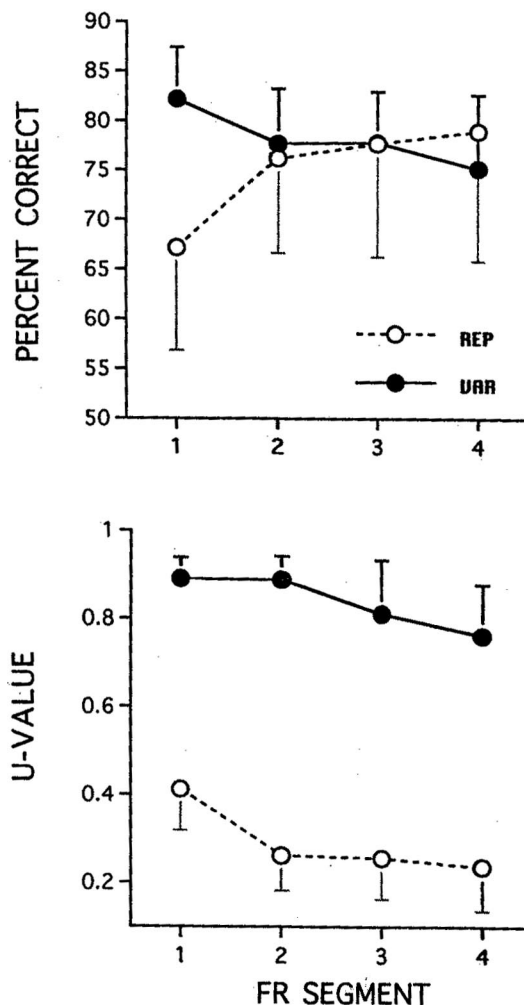
Note. The top graph shows percentage of trials in which a variability contingency was satisfied for groups of VAR (filled circles and solid line) and REP (open circles and dashed line) rats as a function of location within the fixed-ratio (FR) four requirement. The bottom graph shows *U* values, a measure of variability, as a function of the same FR segments. Lines connect group means, and standard deviation is indicated by the error bars. VAR = reinforced for response-sequence variations; REP = reinforced for response-sequence repetitions. From "Reinforced Variability Decreases With Approach to Reinforcers," by C. Cherot, A. Jones, and A. Neuringer, 1996, *Journal of Experimental Psychology: Animal Behavior Processes, 22,* p. 500. Copyright 1996 by the American Psychological Association. Reprinted with permission.

the same fixed-ratio four supraordinate contingencies: These birds had to repeat their sequences four times to gain a single reinforcer (rep group).

Two main findings are important for this discussion. First, the var birds indeed varied significantly more than did the rep birds (Figure 7, bottom graph). Consistent with all of the studies described above, reinforcement of vari-

ability is effective, supporting the claim that if variations contribute to creative work, then reinforcement will have positive effects. However, approach to reinforcement had different consequences for the two groups. Whereas the repetition-reinforced pigeons were increasingly successful as the reinforcer was approached—they repeated more and more as the ratio neared completion—the variability-reinforced birds were decreasingly successful—they were less and less successful at meeting the var contingency. Figure 7 (top graph) shows this difference. Despite the fact that sequence variations were being reinforced, the var pigeons varied less as they approached the reinforcer. Again, assuming that variability plays some role in creativity, these results are consistent with the claim that reinforcement interferes with creativity.

Reinforcement of variability therefore appears simultaneously to exert two effects, with both relevant to creativity: Overall variability is elevated, sometimes to the highest levels, thereby possibly facilitating creative work; but approach to (and possibly focus on) the reinforcers constrains, or lowers, variability, thereby interfering. The overall enhancement of variability was of much greater magnitude than the decrease with approach, but both effects were statistically significant. Disagreement concerning whether reinforcement facilitates or interferes with creativity may partly be due to emphasizing one or the other of these effects. Reinforcers have many influences, each of which must be identified, understood, and invoked.

Psychopathology

Psychopathologies such as attention-deficit/hyperactivity disorder (ADHD), depression, and autism are associated with abnormal levels of response variability. A series of studies asked whether reinforcement can modify such variability in the direction of normalcy.

ADHD. Individuals diagnosed with ADHD are reported to behave more variably than those without that disorder (Barkley, 1990). Mook et al. (1993) studied a possible animal model of ADHD, the spontaneously hypertensive rats (SHRs), comparing them with a control strain, Wystar Kyoto (WKY; Wultz, Sagvolden, Moser, & Moser, 1990). Two questions were asked: Do SHRs respond more variably than WKYs under baseline conditions where reinforcement does not depend on variations, and does reinforcement affect the SHRs in the same way as it does the control WKY strain?

Performances under two conditions were compared, prob and var. In both, four responses across L and R levers constituted a trial, but in the var condition, the current trial was reinforced if it differed from the preceding four trials (Lag 4), whereas in *prob* (similar to yoke), reinforcers were provided at the same frequency but probabilistically and independently of levels of variability. The main result was that SHRs responded more variably than WKYs under both var and prob conditions (i.e., regardless of whether the contingencies required variability, a result consistent with those from the human ADHD literature; Hunziker, Saldana, & Neuringer, 1996; Mook & Neuringer, 1994). As might be expected, when reinforcement required repetitions, the

SHRs performed poorly. However, again paralleling the human case, when amphetamine was administered, a drug with effects similar to one often prescribed for ADHD (Ritalin), reinforced repetitions improved in the SHR strain so that they became as accurate as saline-injected WKYs (Mook & Neuringer, 1994). These studies support SHRs as a model of ADHD (Sagvolden, Pettersen & Larsen, 1993; see, however, Saldana & Neuringer, 1998), but at the same time indicate that the elevated levels of variability in ADHD individuals may not readily be controlled by operant reinforcement.

Depression. Depression is often associated with low variability. For example, Lapp, Marinier, and Pihl (1982) found that depressed women produced fewer alternative solutions to hypothetical problems than nondepressed women (see also Channon & Baker, 1996). Horne, Evans, and Orne (1982) found that responses generated by depressed patients were more predictable than those by controls, when they were asked to call out numbers randomly. These experimental results are consistent with clinical observations.

Can reinforcement increase variability in depressed individuals? Hopkinson and Neuringer (2003) divided college students into mildly depressed and not depressed, based on the Center for Epidemiological Studies Depression Scale (Radloff, 1991), a paper-and-pencil self-evaluation index. Each participant played a computer game in which responses were first reinforced independently of variability (prob), following which (without informing the participants) variable sequences were reinforced (var). Under prob conditions, the depressed students' variability was significantly lower than the controls. Under var, variability increased in both groups until, by the end of training, the depressed and nondepressed participants' responses were indistinguishable (Figure 8). This result, if general, is important because it indicates that variability can be explicitly reinforced in those manifesting mild depression. Of course, additional studies are necessary to test other populations, including more severely depressed. However, the finding is consistent with therapies that are directed at increasing variability (Beck, 1976).

Autism. More extreme response stereotypes characterize individuals with autism (Hertzig & Shapiro, 1990). Often cited are stereotypic movements, such as hand waving or head bobbing, but repetitive operant responses are also observed. For example, Baron-Cohen (1992) asked children to hide a penny in one hand so that the experimenter could not guess the location. Those diagnosed with autism were more likely than controls to respond predictably, such as repeatedly switching back and forth from L to R hands (see also Mullins & Rincover, 1985). Miller and Neuringer (2000) asked whether reinforcement of variations might help to overcome such stereotypes. Five individuals diagnosed with autism and nine control participants pressed large buttons in front of a computer screen. At first, sequences were reinforced independently of variability (prob phase), following which reinforcement was contingent on sequence variations (var phase). (Reinforcers for the control subjects were toys or money and for those with

Figure 8
Levels of Variability (Indicated by U Value) for Depressed and Not-Depressed College Students When Reinforcers Are Provided Independently of Response Variability (PROB Phase) Versus When Variations Are Required (VAR Phase)
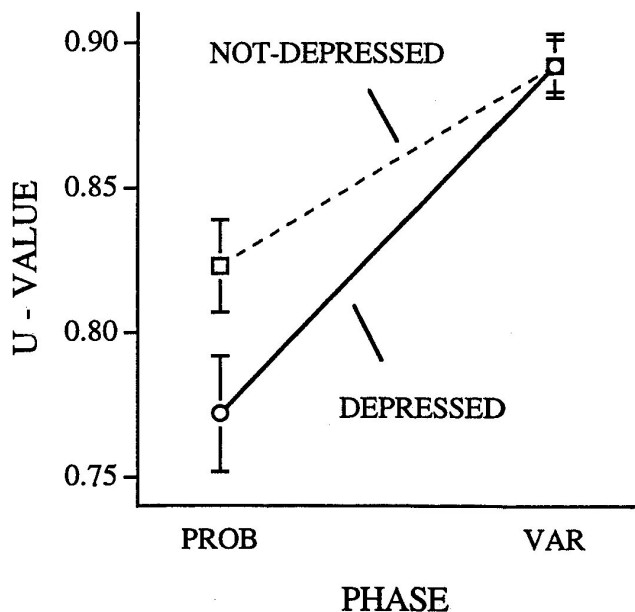
Note. Standard errors are shown by the error bars. From "Modifying Behavioral Variability in Moderately Depressed Students," by J. Hopkinson and A. Neuringer, 2003, *Behavior Modification, 27*, p. 260. Copyright 2003 by Sage. Reprinted with permission.

autism were individually defined.) The results showed that the participants with autism varied significantly less than control subjects throughout the experiment, but when reinforced, variability increased significantly in both groups. This finding is important because it indicates that some of the behavioral stereotypes that are characteristic of autism may be modified by reinforcement of variations. Lee, McComas, and Jawor (2002) provided supporting evidence. Three individuals with autism were reinforced for varying their verbal responses to questions—the responses had to be appropriate given the context—and appropriate variability increased in two of the three individuals. Therefore direct reinforcement of functional variability may help to modify ritualistic and stereotyped behaviors.

Implications

Voluntary Action

A long-standing question for philosophers, psychologists, and biologists concerns the nature of "voluntary" action. Operant variability has two characteristics that may provide clues, each of which will be discussed.

First, an individual who manifests voluntary behavior is able to respond in a way that even the most knowledge-able observer cannot predict, such unpredictability helping to distinguish voluntary action from reflexes and involuntary responses generally. (I assume, as did Epicurus, James, Fechner, and Skinner, that the difference between voluntary and involuntary is real.) Of course, the voluntary actor often responds in predictable fashion (e.g., brushing teeth in the morning, answering the phone when it rings, or stopping at a red light). But in these cases, as in all other cases of voluntary behavior, contingencies of reinforcement and cues can affect the probabilities (e.g., as in *The Dice Man* novel, an individual may break habitual niches, and predictions of behaviors then become less certain). In more technical terms, I posit that levels of predictability and unpredictability can change under the influence of reinforcement contingencies and discriminative cues and that appropriate changes in these levels is a hallmark of the voluntary act. For example, if the police officer asks someone his or her name, then he or she is likely to answer truthfully, that answer being readily predicted. In the context of a "fool the questioner game," the answer to the same question might be quite unpredictable. Thus, an observer is able to predict the response to exactly the same question in one context but not another.

This ability to behave more or less predictably is related to the second defining characteristic of voluntary acts. Variability will not alone suffice: Neither dice nor atomic emitters are voluntary actors. The second characteristic is functionality (i.e., as manifest by attempts to satisfy a need, attain a goal, or be reinforced). Voluntary responses can (in retrospect, if not beforehand) be explained by their relationship to conditions, contexts, or reinforcement contingencies. For example, in answer to "Why did you go to that particular movie?" the answer might be "To get a good laugh." Four different movies might have been under consideration, and possibly the decision was made stochastically, but a good explanation would have been possible for any of the choices. The important point is that even if voluntary choices are generated stochastically, they are members of classes (perhaps Fechnerian or Skinnerian), each of which would satisfy a current need. Thus voluntary responses are potentially unpredictable, functional behaviors.

Voluntary behaviors and operant responses therefore have characteristics in common, a point made in a somewhat different fashion by Skinner (1974). The operant class provides the functionality of voluntary acts, and within-class stochasticity provides the unpredictability. This combination of functionality and unpredictability helps to explain why operant responses are often referred to as voluntary (see Neuringer, 2002).

Everyday Behavior

Knowledge concerning operant variability can be applied to everyday affairs. As just indicated, many activities are repetitive or stereotyped, from paths people take, things they say, foods they eat, to interactions with colleagues, friends, and families. Conceptualizing behaviors as members of sets of possible responses, some of which may be more functional than habitual actions, may motivate one to

vary. The consequence of varying will often be informative. When trying but failing to relax, think of alternatives to normal attempts. When trying to quit smoking, think of smoking as only one member of a larger class of potentially satisfying responses. Johann Sebastian Bach's musical variations can serve as a model, with individual variations often being unexpected and yet functional. Bachian behavior combines variability (and unpredictability) with functionality.

But how does one go about varying? Researchers cannot yet answer that question, just as they cannot explain how individuals initiate any operant response, such as lifting an arm or uttering a word. One learns to do it. Similarly, one learns to vary operantly with consequences playing an important role. There may be additional contributors as well. For example, Stokes and coworkers (Stokes, 2001; Stokes & Balsam, 2001; Stokes & Harrison, 2002) showed that constraining (or defining) a class of responses may have the somewhat counterintuitive effect of increasing levels of variability. This result may be due to the fact that operant variability often depends on stochastic emergence from within a class. Behavioral specification of the class may therefore facilitate variability because, without such specification, the behavior may tend to its favored or most probable condition (as under yoke contingencies).

Another way to influence variability may be through modifications of response speed, as described above. For a given level of expertise, as one responds more rapidly, behaviors may become more repetitive and predictable. Thus, to increase the variations in one's daily life, slow down.

A third contributor to operant variability may be attention. Studies in which human participants are asked to generate random numbers show that, although people are generally unable to meet the requirement of randomness (except when explicitly reinforced for so doing, as discussed above), they are better able to approximate a random sequence when attending to the task than when attention is divided (Baddeley, Emslie, Kolodny, & Duncan, 1998; Evans & Graham, 1980). Thus, attending to one's activities may lead to an increase in functional variations (see Langer, 1989).

But perhaps most important, reinforcement can be applied. Individuals can support—reinforce—in themselves and in others, levels of variability from which surprisingly functional actions emerge.

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