

Variability is thought to be necessary for the shaping of operant responses (Baum, 1994; Glen, Ellis, & Greenspoon, 1992; Palmer & Donahoe, 1992; Skinner, 1984). For example, "Variability in behavior provides the means by which a totally new behavior, never performed by an individual before, can gradually be developed" (Mazur, 1998, p. 131). An important question for those who attempt to modify behaviors in the world outside of the laboratory concerns sources of such variability. More precisely, How can one generate the variability necessary for shaping to succeed?

There is inherent variability in all behavior, but it does not always suffice to generate reinforceable instances, and, moreover, a trainer of new behavior does not have control over this "endogenous" source.

An alternative is for trainers to withhold reinforcement; many studies have documented increased variability in extinction (Antonitis, 1951; Balsam, Deich, Ohyama, & Stokes, 1998; Neuringer, Kornell, & Olufs, 2001). However, responding decreases during extinction, sometimes to zero levels, and previously reinforced responses often persist. During shaping, it is necessary that responding be both variable and maintained, and, therefore, reinforcement must be provided, at least occasionally. It is more relevant to ask, What happens when reinforcement is temporarily withheld or when reinforcement frequency is lowered, but not

to zero levels? The evidence here is mixed, some studies reporting increased variability when reinforcement frequencies decrease (Boren, Moerschbaecher, & Whyte, 1978; Tatham, Wanchisen, & Hineline, 1993; Tremont, 1984), but others showing small or no effects (Eckerman & Lanson, 1969; Herrnstein, 1961; Machado, 1989).

A third source of the requisite response variations might be reinforcement contingent on variability itself. Although direct reinforcement of variability has only rarely been discussed as a contributor to operant shaping (see Neuringer, 1993; Stokes & Balsam, 1991), there is substantial evidence showing that variability can be reinforced (Blough, 1966; Bryant & Church, 1974; Machado, 1989; Page & Neuringer, 1985; Pryor, Haag, & O'Reilly, 1969).

A question of importance is, Which of these putative sources of variability contributes most to the variability required to train new operants? Two studies compared the variability generated by different reinforcement frequencies with that generated

highly variable. The contingencies were parametrically less demanding for three other groups, with the last requiring minimal variation. All groups were first trained under continual reinforcement (CRF) conditions, in which every success in meeting the contingency was reinforced, following which reinforcement frequency was decreased to a variable interval of 1 min (VI 1), in which meeting the respective contingencies was reinforced on the average of no more than once per minute, and then to a variable interval of 5 min (VI 5), with a final return to VI 1. The goal was to test whether reinforcement contingency in fact exerts greater control over response variability than does reinforcement frequency.

Since we found greater control by contingencies than by reinforcement frequencies in Experiment 1, we further studied the effects of parametric differences in variability contingencies on the acquisition of a particular sequence of responses in Experiment 2. The main question was, How do different levels of baseline variability affect learning?

## EXPERIMENT 1

### Method

#### Subjects

Forty male Long-Evans rats, 4 months old at the start, were housed in pairs, with free access to water and a 12:12-h light:dark cycle. The rats had previously been trained to press levers for food. Experimental sessions were provided 5 or 6 days a week, with free access to food for 1.5 h after each session and for the same duration during nonexperimental days.

#### Apparatus

Ten modified Gerbands operant chambers were used (details in Neuringer et al., 2001). On the front wall, two levers, each 5.1 cm wide, 5 cm above the floor, with 8.9 cm between them, were designated right (R) and left (L), with a 28-V DC light above each. A pellet tray between the two levers provided access to 45-mg Noyes pellets. Three pigeon keys, each 2 cm in diameter and 9 cm above the floor, were located on the rear wall; the middle key (K) illuminated with 28-V DC lights (the other two keys not being used in this experiment). A tube protruded 10 cm below the center of the chamber ceiling, providing continuous access to water, and an overhead 28-V bulb served as the houselight.

#### Procedure

A trial consisted of three responses across the three operanda. Trials ended with reinforcement if a variability contingency had been met, and there was a brief timeout otherwise. A different level of sequence variability was required to meet the contingencies for each of the four groups. In the first phase, reinforcement was provided each time the variability contingencies were satisfied. In later phases, reinforcement frequency was decreased.

**Variability contingencies.** With three operanda (two levers and one key) and three responses per trial, 27 different sequences were possible (e.g., KKK, RKL, LLR). A sequence was reinforced only if its weighted relative frequency was less than a threshold value. The relative frequency of a sequence was calculated by dividing the number of times the sequence had been emitted by total trials. All sequence frequencies were multiplied by a weighting coefficient of .98, applied after each reinforcement (for details, see Denney & Neuringer, 1998). This weighting caused recent sequences to contribute more to the assessment of relative frequencies than did sequences emitted earlier. Data for these calculations were carried over from one session to the next.

The weighted relative frequency of the emitted sequence was compared with a threshold to

variability contingency, the others were reinforced for meeting the .055, .074 and .37 contingencies, respectively). Following the VI 5 condition and after 1 month with no experimentation, the subjects were returned to VI 1 for five sessions, in order to see whether performances would return to previous VI 1 levels.

**Measures**

Sequence variability was evaluated with the U-value statistic, computed as follows:

where  $n$  equals the number of sequences

toward the original VI 1 levels, indicating that the results were due to reinforcement rather than an artifact of order of experience. These transition effects therefore support the conclusions based on across-session averages presented above.

Figure 3 provides further support for these conclusions. Shown are the relative frequencies of each of the 27 sequence patterns (frequencies of each sequence divided by total sequences per session), averaged over the last three sessions. The ordering is from most frequent on the left to least on the right. As the contingencies became more demanding across groups (from top to bottom panels), the distributions broadened and flattened, indicating increasingly equal emission of sequence patterns and correspondingly increased variability. The three curves in each

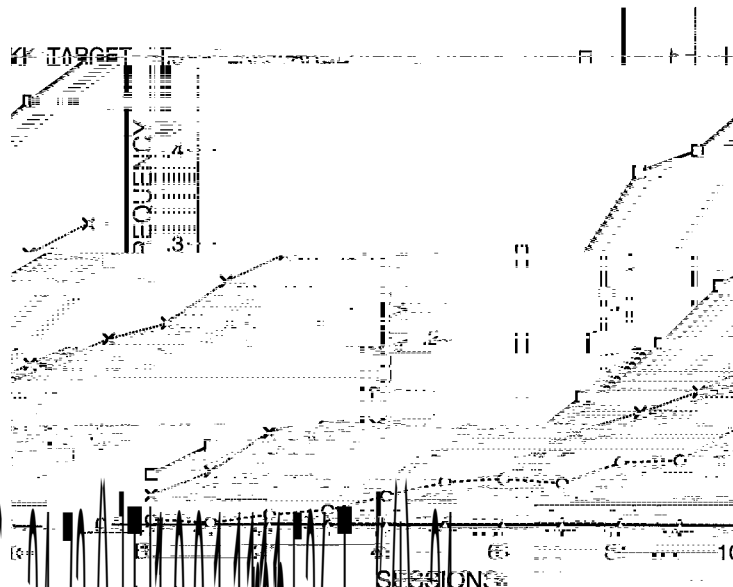
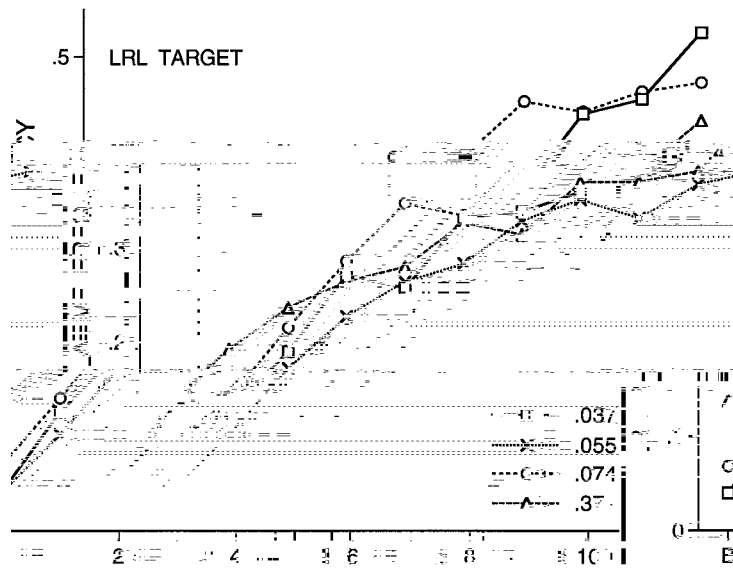
### Figure

variability was intermittently reinforced, whereas a particular sequence of responses (referred to as the target sequence) was concurrently reinforced whenever it occurred. The goal of these studies was to find out whether reinforcement of variable response sequences facilitated acquisition of a particular target sequence. The subjects learned to emit the target response sequence faster than did control subjects who were never reinforced for variations. Little is known, however, about the parameters im-

portant to the observed facilitation. It is not known, for example, whether the levels of baseline variability affect speed of acquisition. The present experiment employed the same variability contingencies used in Experiment 1. Reinforcement was provided intermittently (VI 1 min) for variations and, concurrently, whenever a preselected target sequence was emitted. The main question was whether levels of reinforced variability would affect the learning of operant sequences.

Subjects

Method



viously, different and more complex response sets, and a wider range of parameter values. The results confirmed the Blough (1973) findings and extended them in important ways. Contingencies controlled sequence variability: Level of emitted variability was a direct function of the level required by the reinforcement contingencies. Frequency of reinforcement exerted only small effects, the direction of these effects depending in part on the contingencies.

Some previous studies reported that behavioral variability increased as reinforcement frequencies decrease (Boren et al., 1978; Tatham et al., 1993; Tremont, 1984). We found this to be the case only when initial levels of vari-

ability were low, as characteristic of previous studies. The opposite was found when initial levels of variability were high.

These findings have implications for the study of variability in human and nonhuman behavior. They suggest that variability is not simply a function of reinforcement frequency, but is also a function of the level of variability required by the contingencies. This has implications for the study of variability in human and nonhuman behavior.

Experiment 2 supported this hypothesis by showing that reinforced variability facilitated learning of difficult-to-learn operant response sequences (Neuringer, 1993; Neuringer et al., 2000). As in Experiment 1, four different variability contingencies were employed, requiring high, intermediate, and low variability, but now, in addition, a particular sequence was identified as the to-be-learned target, and it was reinforced whenever it occurred. All subjects, whether their variations were high or low, learned

an easy target sequence, with the high-variability group (.037) learning fastest. When a difficult sequence served as the target, learning was directly correlated with variability: The higher the variability, the faster the learning. Indeed, the group that experienced the most permissive contingencies (and therefore varied least) continued to emit the previously reinforced, but no



variability helps subjects both to learn new response sequences and not to emit previously established, but no longer functional, sequences. The results are also consistent with other findings that learning is correlated with periods of high behavioral variability—for example, when learning motor skills (Manoel & Connolly, 1995) and cognitive strategies (Siegler,