NUMBER OF PRIOR REPETITIONS OF OPERANTS, AND RESURGENCE

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In a series of nine experiments, human participants typed non-word sequences of letters on a computer keyboard. Each sequence was initiated by a spacebar press and ended by a press of the enter key, and was treated as a "revealed operant." Each such operant contained criterial (mandated) and noncriterial (discretionary) keystrokes. Participants learned several unique operants of this type, each defined by a different criterial keystroke pattern. Experiments consisted of several learning sessions and a final "test" session. The objective was to determine the effect of varying the number of repetitions required for each operant during the learning sessions on the relative emission frequency of those operants during the test session, and on the resurgence characteristics of their noncriterial keystroke sequences. It was found that the number of repetitions previously required for an operant did not generally affect the occurrence of that operant during the test session <u>unless</u> the absolute number of prior repetitions was high enough. The steepness of the ratio of the relative numbers of repetitions of various operants did not affect this result. Resurgence in the test session was measured by determining when, in the participant's prior history, each noncriterial keystroke sequence had previously been used, a measurement of that sequence's "antiquity". A higher antiquity level represents an older noncriterial keystroke sequence. It was found that higher-than-average levels of resurgence during the test session were reliably associated with invalid operants and with operants (both valid and invalid) practiced less often during the learning sessions.

The relationship between the number of times an operant was emitted and its subsequent strength has been addressed previously via studies that used operants defined by single switch closures (such as bar presses or key pecks) and that examined resistance to extinction (Dyal & Holland, 1963; Kass & Wilson, 1966; Lewis & Duncan, 1958; Perin, 1942; Senkowski, 1978; Tombaugh, 1967) or responding in the presence of free food, known as contrafreeloading (Bilbrey, Patterson & Winokur, 1973; Jensen, 1963; Jensen, Leung & Hess, 1970; Lentz & Cohen, 1980; Stolz & Lott, 1964). These studies produced conflicting results.

In addition, many studies have measured the effect of amount of prior training on the degree of control that a stimulus acquires, by using discrimination or generalization tasks (Farthing & Hearst, 1968; Hearst & Koresko, 1968; Rilling & Budnik, 1975; Sewell & Nickel, 1979; Thomas & Williams, 1963) and reversal (Lovejoy, 1966; Mackintosh, 1965, 1969; McAllister, Capehart & Rogers, 1970; Reid, 1953). In general, results from this body of research show that additional training (or "overtraining", as it is sometimes called) improves stimulus control and leads to faster reversal, although this effect is far from simple and there are conflicting results.

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While frequency of exposure to a stimulus is not the same as frequency of repetition of an operant, it is somewhat analogous, and the extensive stimulus exposure literature is therefore worth citing. Most of the relevant studies have examined the effect of number of exposures to stimuli on later "preference" for those stimuli, using paintings, nonsense words, Chinese characters or geometric shapes (Hamid, 1973; Maslow, 1937; Zajonc, 1968). There is also a large body of "memory" research on the relationship between frequency of exposure to a stimulus and later recall of that stimulus. The general finding is that repetition of an item to be learned facilitates later recall (Ebbinghaus, 1885; Liu & Ma, 1970; Nelson, 1977). On the other hand, some experiments have shown no effect of repetition on recall (Craik & Watkins, 1973; Hall & Buckolz, 1982; Jacoby, 1973).

The present studies address, for the first time, the relationship between number of repetitions of operants and their subsequent strength by using different but roughly equivalent operants repeated different numbers of times.

The independent variable here is the number of times each of several different but equivalent operants were repeated in the participant's previous history, and the dependent variable is the number of times those same operants were emitted in a final test session in which the experimental conditions were made “stressful”. In examining the operants emitted in the test session, both the criterial characteristics of those operants (i.e. the characteristics that define the operant) and noncriterial characteristics (i.e. characteristics not included in the definition) were examined.

The term resurgence has previously been applied to the recurrence of operants or their characteristics (Epstein, 1985). Resurgence is defined as the reappearance of operant behavior patterns, or entire operants, emitted earlier in a participant's learning history but not in the more recent history. Resurgence is of interest because much of the variability in any behavior stream, including minor deviations from practiced routines and noticeable errors made during performance of skilled behavior, may be instances of resurgence.

Prior studies have shown that resurgence occurs when extinction is instituted (Epstein, 1985; Mechner, Hyten, Field & Madden, 1997). However, resurgence is not merely an extinction-induced phenomenon, as differences in contingencies or in the nature and amount of reinforcement during acquisition can affect the amount and nature of resurgence during extinction (Dixon & Hayes, 1998; Pittenger, Pavlik, Flora & Kontos 1988). Resurgence is also observed when a participant’s work requirement is abruptly raised (Mechner et al, 1997), and resurgence of derived relations has been documented under restricted choice conditions in research on equivalence classes (Wilson & Hayes, 1996).

The present experiments use the revealed operant technique (Mechner, 1992; Mechner et al, 1997) to study resurgence since this technique permits tracking of both criterial (mandated) and noncriterial (optional) attributes of each individual occurrence of an operant. The revealed operant is a research preparation consisting of a sequence of actions whose beginning and end is marked by behavioral events. Some of these actions (sub-operants) are specified (by the experimenter) as criterial and some as noncriterial.

All operants have both criterial and noncriterial dimensions. The criterial aspects of an operant are those that must occur for the operant to be considered as having occurred (for example, the number of degrees a rat must depress a lever). Noncriterial aspects are all the other characteristics of that operant, including topographic ones. Variability in noncriterial dimensions of an operant has been shown to increase during extinction in successive conditioning-extinction cycles (Antonitis, 1951). Variability levels during extinction, in turn, are affected by the topography chosen for the response (Morgan & Neuringer, 1990).

All of the experiments discussed here followed the same general procedure: Participants learned different but equivalent operants during several learning sessions, practicing some operants more often than others, and were then allowed to choose which operants to perform during a final session in which accuracy and speed contingencies were imposed.

METHOD

Participants

The participants were mostly university students, both male and female, ranging in age from 18 to 57.

Each experiment consisted of five to nine “learning sessions” in which the participants learned and practiced the required operants, followed by a final “test session”. Participants completed one session per day, with all of each participant’s sessions taking place at the same time each day. They were told they would be paid $10 per session completed and, in addition, could earn up to $200 during the test session, with the amount earned depending on their performance. They signed consent forms agreeing to keep such factors as caffeine consumption and amount of sleep consistent from day to day during the course of the experiment.

Apparatus

The experimental room contained four computer workstations separated by screens. Each of the computer keyboards was fitted with a particleboard “mask” that covered all the keys except for those used in the experiment: 12 character keys (tyuighjkvbnm), the space bar, the enter key, the number keypad, and four function keys.

Procedure

General Procedure

The particular revealed operant used in this series of experiments consisted of a non-word sequence of 12 or more letters. Each operant was initiated by pressing the space bar and ended by pressing the enter key. The first three and last three letters of each sequence were mandated (criterial), and defined a unique operant. In some of the experiments, participants learned and practiced nine different operants, and in others they learned six (see Table 1).

Participants were required to type at least six keystrokes between the first and last three letters of the sequence. For these six or more middle keystrokes, participants could type any letters from the set of twelve available character keys.

For example, to complete the operant VYN KUB, participants were required to perform the following sequence of keystrokes: space bar, “V”, “Y”, “N”, six or more of any of the letters available, “K”, “U”, “B”, enter key.

During the learning sessions, only one operant was acceptable at any given time; the computer was programmed to switch the required operant after every “block” of 20 to 30 successful operants. The order in which the different operants were required was arranged to be unpredictable to the participants.

Operants were considered valid if they fulfilled the definitional criteria, i.e. they began with the space bar press, ended with the enter key press and contained 12 or more letters with the first and last three matching the specific criterial pattern in use. Invalid operants were not counted toward the total required in order to finish a block or the session, thus ensuring that each participant would type each of the operants correctly the number of times required by the experimental design.

The computer monitor displayed a visual cue (the monitor screen turned from black to blue) at the instant the participant initiated an operant. During the learning sessions the computer also displayed another visual cue – a green square in the middle of the screen – every time a valid operant was completed. At no point in any of the sessions did the monitor display the characters typed by the participants.

Before the first session began, the experimenter instructed the participants regarding the procedure for completing a valid operant. During the first session, participants were also given explicit instruction by the computer, in the form of a message displayed on the screen, as to which of the different operants would be accepted. After the first learning session, the experimenter told the participants that they would no longer receive these messages and must try different operants until they found the one that produced the green square. Participants who asked in advance about the nature of the test session were told only that the amount of money earned on the final day would depend on their accuracy, speed, and how well they remembered the patterns of letters.

In all nine experiments, some of the operants were required more often than others during the learning sessions (without the participants being explicitly informed of this fact). In each experiment, the operants were grouped into three categories of repetition frequency. In some experiments there were two and in others three operants per category. The three categories were those required least often (“lowest-repetition”), those required an intermediate number of times (“medium-repetition”), and those required most often (“highest-repetition”). The independent variables were the different absolute numbers of repetitions required during the learning sessions for each category and also different ratios (1:2:4 and 1:3:9) of relative number of repetitions among the three categories (see Table 1).

The experiments used two different formats for the test session, in order to determine whether, and if so how, the results would depend on the type of test session used. In five of the experiments, participants were allowed to use any of the operants during the final session, provided they did not type one of the immediately preceding three (Page & Neuringer, 1985). They were thus forced to vary the operants they used rather than type the same one over and over, as they may have done during the learning sessions.

In the other four experiments, the ban on repetition of an operant during the final session was lifted, but participants were limited to a subgroup of only three operants in any given block – one per repetition-frequency category. At the beginning of the test session three of the nine possible operants were displayed on the computer screen, one from each of the three categories (lowest-repetition, medium-repetition and highest-repetition). After every block of 20 operants the computer displayed a new set of three acceptable operants, always consisting of one operant from each of the three categories, with the exception of a few “control blocks” which presented more than one operant from a category, just to check whether a participant showed any bias for or against any of the individual operants. Operants chosen during these control blocks were not counted when compiling the data.

In both types of test session the green square was not presented and valid operants instead produced money, provided they were executed quickly enough, while invalid or too-slow operants resulted in a loss of money.

At the beginning of the test session the participants were instructed by the experimenter that each monetary award must be “rung up” by typing the amount on the number keypad, followed by pressing the enter key. Every time money was presented the computer emitted a “beep” tone and the following message appeared on the screen: “You just earned 65 cents. Ring it up." Completion of this action was required before the participant could continue with the next operant. Continuously displayed in the upper left corner of the monitor was the total amount that had been earned by the participant up to that point. Whenever money was lost, the amount was deducted automatically, with an accompanying low tone distinct from the “ring it up” beep.

Individual Experiments

Table 1 shows the ratio of numbers of relative repetitions for categories of operants during learning sessions and type of test session for each of the nine experiments in the series. Experiments 8 and 9 are almost identical; the only difference between them being that in Experiment 9 the same six operants were assigned to different repetition-frequency categories in order to control for possible individual operant preferences.

Table 1

Experiment	Number of Operants	Number of Operants per Category	Repetitions Required for 3 Categories	Type of Final Test Session
1	9	3	120/240/480 reps (1:2:4 ratio)	Free choice; no repetition allowed
2	9	3	99/297/891 reps (1:3:9 ratio)	Free choice; no repetition allowed
3	9	3	120/240/480 reps (1:2:4 ratio)	Free choice; no repetition allowed
4	9	1	20/40/80 60/120/240 180/360/720 reps (1:2:4 ratio) and 20/60/180 40/120/360 80/240/720 reps (1:3:9 ratio)	Rotating groups of 3 valid patterns
5	6	2	234/468/936 reps (1:2:4 ratio)	Free choice; no repetition allowed
6	6	2	104/312/936 reps (1:3:9 ratio)	Free choice; no repetition allowed
7	6	2	104/312/936 reps (1:3:9 ratio)	Rotating groups of 3 valid patterns
8	6	2	234/468/936 reps (1:2:4 ratio)	Rotating groups of 3 valid patterns
9	6	2	234/468/936 reps (1:2:4 ratio)	Rotating groups of 3 valid patterns

Of the nine experiments listed, Experiment 4 is unique in that its independent variables were two different ratios of repetitions at three different absolute value levels within the same experiment. This was achieved by having only one operant for each repetition-frequency category, as shown in Table 2. During the test session, relative emission frequency of the three levels at the 1:2:4 ratio of repetitions was tested by presenting participants with a choice between operants one, two and three; operants four, five and six; and operants seven, eight and nine. The three levels of the 1:3:9 ratio were tested by using groups consisting of operants one, four and seven; two, five and eight; and three, six and nine.

Table 2

Operant Seven 180 repetitions	Operant Eight 360 repetitions	Operant Nine 720 repetitions
Operant Four 60 repetitions	Operant Five 120 repetitions	Operant Six 240 repetitions
Operant One 20 repetitions	Operant Two 40 repetitions	Operant Three 80 repetitions

Each of these experiments had two main objectives:

1. To study the effects of number of prior repetitions of operants during learning sessions on the emission frequency of those operants during the test session.

2. To study the occurrence and characteristics of resurgence of noncriterial patterns of keystrokes emitted during the test session, and the relationship of such resurgence to the number of prior repetitions of the operants in which those patterns occurred.

RESULTS

Results for each of the objectives listed above are presented separately:

<u>1. Impact of Prior Repetition on Subsequent Emission Frequency</u>
During the test session, the percentage of operants selected from each category was measured. The results did not appear to depend on which of the two types of test sessions was used.

In general, operants that were required most often during the learning sessions (the highest-repetition category) occurred more often during the test session than those required least often (the lowest-repetition category), <u>but only</u> if the absolute number of repetitions required for the highest-repetition operants during the learning sessions was high enough (at least 720). During the test session of Experiment 3 (in which the three categories of operants had previously been required 120, 240 and 480 times respectively, a 1:2:4 ratio of relative repetitions), six of the seven participants showed no preference for any category – they typed all operants almost equally often [**Figure 1**].

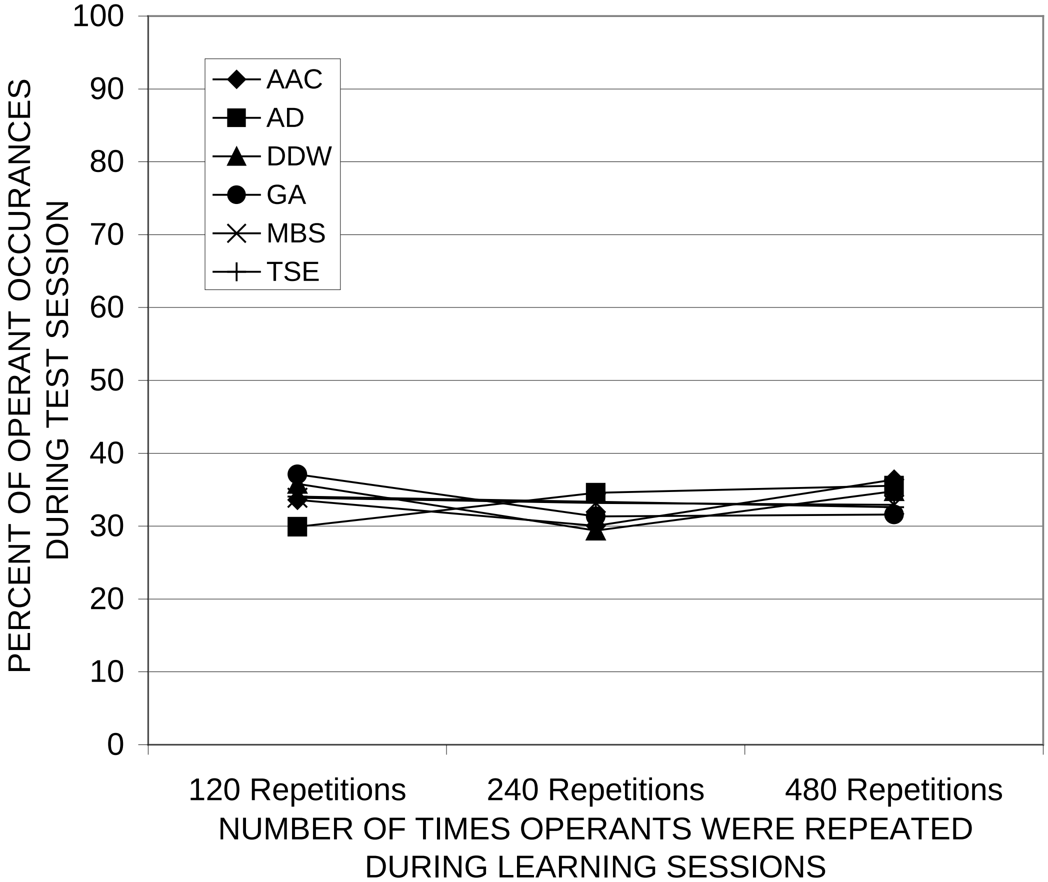

Figure 1. Frequency with which the three categories of operants occurred in the test session, as a function of number of times they were required to be repeated in the learning sessions, for six of the seven participants in Experiment 3. When the number of repetitions for the highest-repetition category was 480 or less, there was little or no difference in frequency of occurrence.

In Experiment 1, there is a slight preference for the highest-repetition operants but only in four of the seven participants, for only two of which the effect is statistically significant. [**Figure 2**].

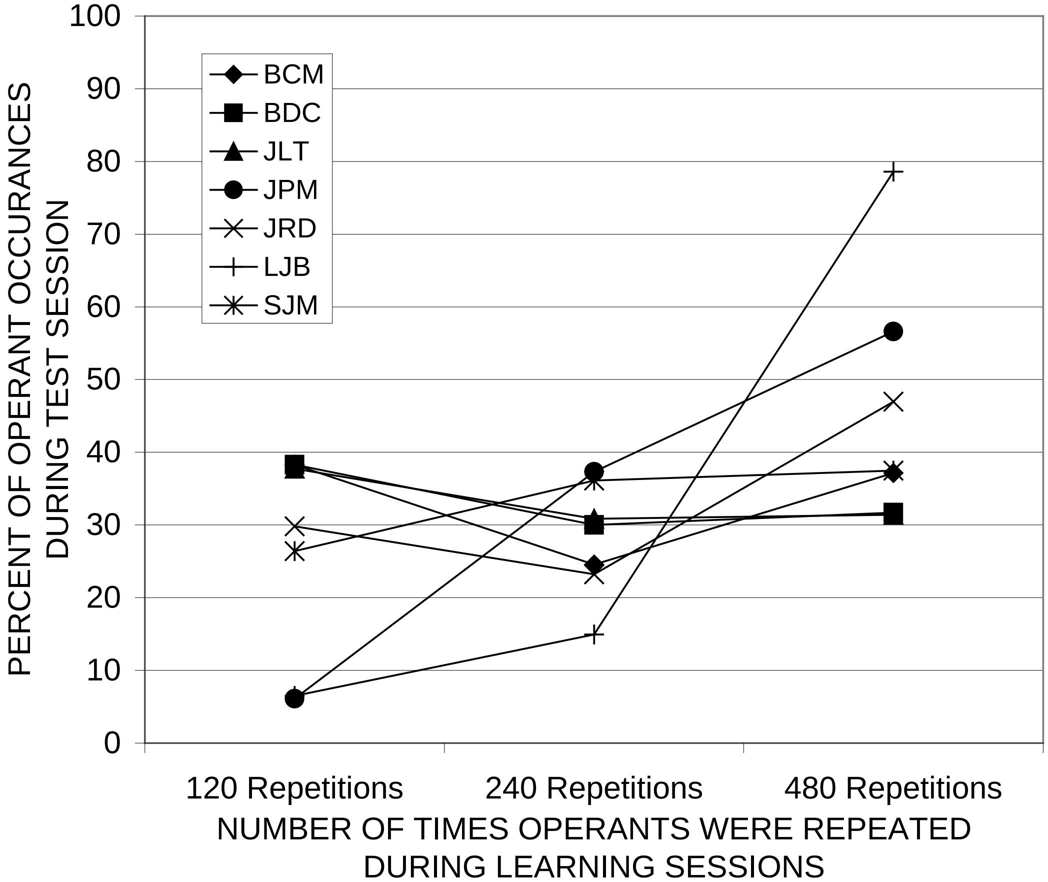

Figure 2. Frequency with which the three categories of operants occurred in the test session, as a function of number of times they were required to be repeated in the learning sessions, for the seven participants in Experiment 1. For only two of the seven participants, the 480-repetition category showed a higher frequency of occurrence.

By contrast, in Experiment 5 (also using a 1:2:4 ratio, but with much higher absolute numbers of prior repetitions: 234, 468 and 936), all seven participants showed a considerably higher emission frequency for the highest-repetition category during the test session [**Figure 3**].

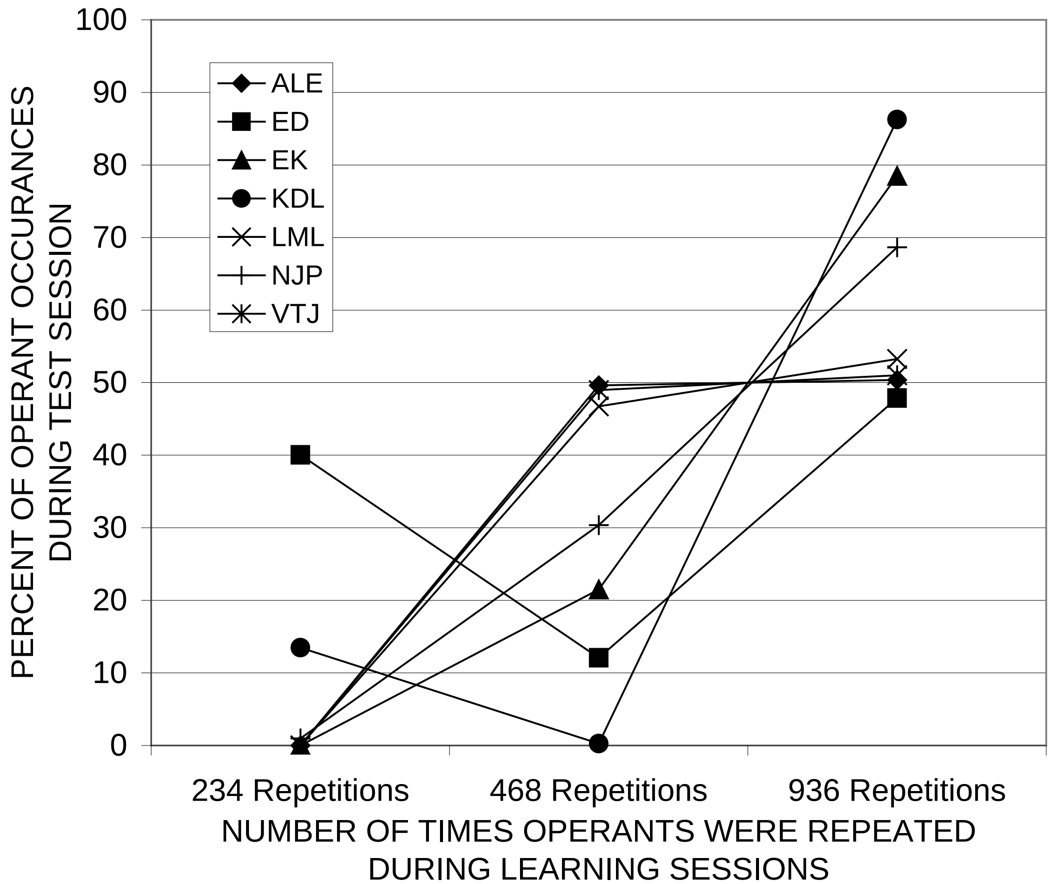

Figure 3. Frequency with which the three categories of operants occurred in the test session, as a function of number of times they were required to be repeated in the learning sessions, for the seven participants in Experiment 5. For all seven participants, the 936-repetition category showed a markedly higher frequency of occurrence than the lower repetition categories.

The results of Experiments 8 and 9 were almost identical, with highest-repetition operants occurring more frequently for six out of seven, and seven out of nine, participants respectively [**Figures 4 & 5**].

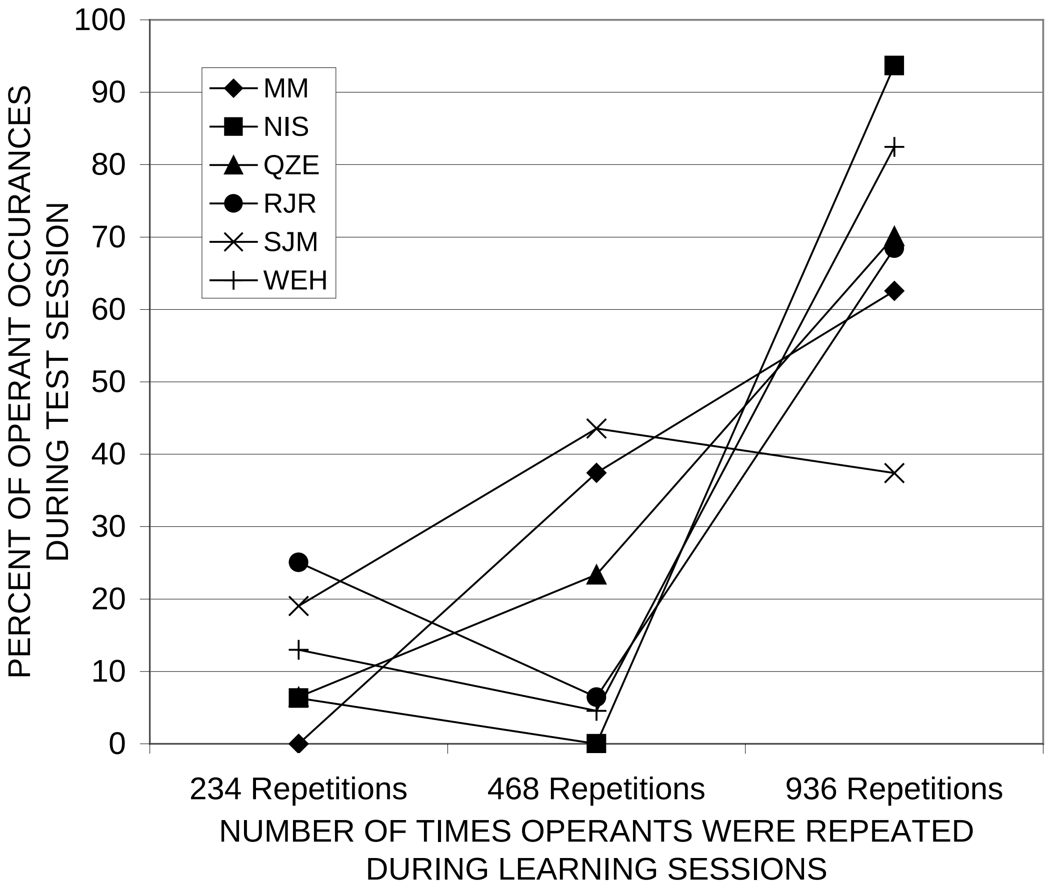

Figure 4. Frequency with which the three categories of operants occurred in the test session, as a function of number of times they were required to be repeated in the learning sessions, for six of the seven participants in Experiment 8. Again, for these six participants, the 936-repetition category showed a markedly higher frequency of occurrence than the lower repetition categories.

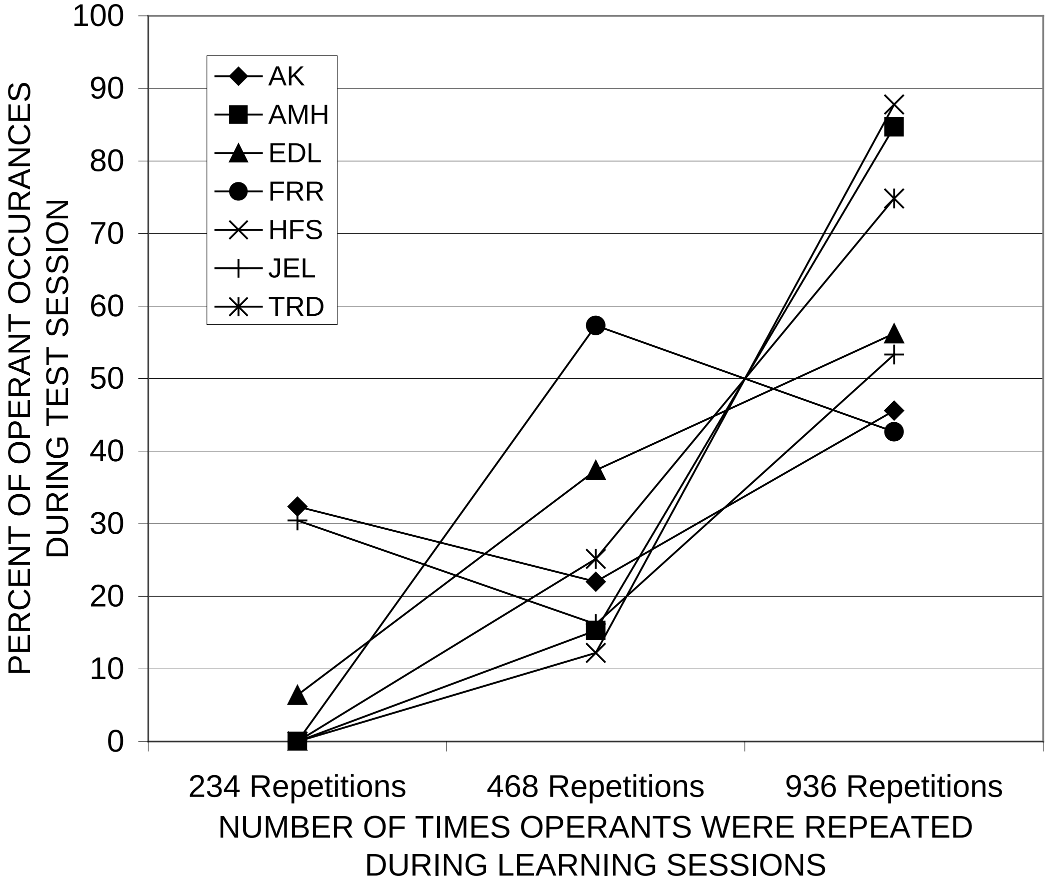

Figure 5. Frequency with which the three categories of operants occurred in the test session, as a function of number of times they were required to be repeated in the learning sessions, for seven of the nine participants in Experiment 9. Again, for these seven participants, the 936-repetition category showed a markedly higher frequency of occurrence than the lower repetition categories.

Switching the specific operants required for the highest-repetition category in these two experiments made no difference in the results, thus ruling out preferences for individual operants as the explanation of the results.

The ratio of the relative number of prior repetitions of the three categories did not appear to be a significant factor. In both Experiments 6 and 7, which utilized a 1:3:9 ratio among the categories, results were comparable to the above-mentioned 1:2:4 ratio experiments: During the test session five out of seven and six out of seven participants demonstrated a higher emission frequency for the highest-repetition operants [**Figures 6 & 7**].

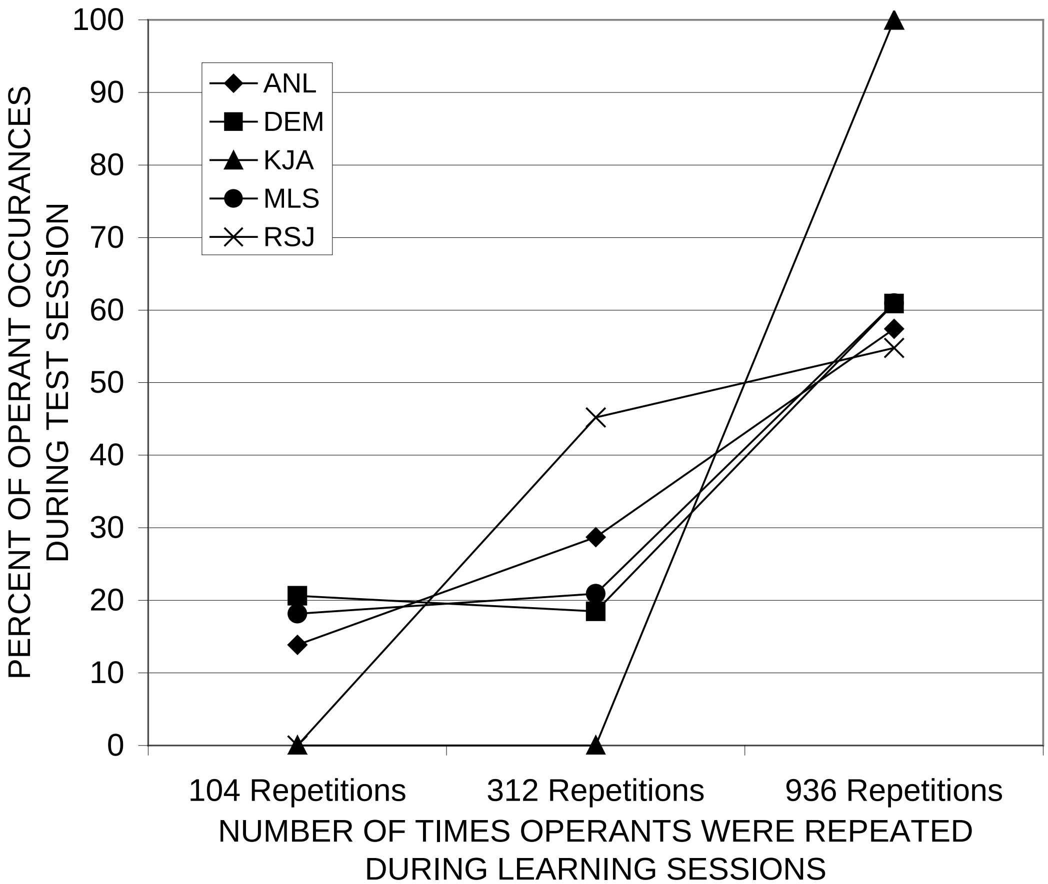

Figure 6. Frequency with which the three categories of operants occurred in the test session, as a function of number of times they were required to be repeated in the learning sessions, for five of the seven participants in Experiment 6. Here the three repetition categories were in a 1:3:9 ratio rather than the 1:2:4 ratio used in the previous experiments. Again, for these five participants, the 936-repetition category showed a markedly higher frequency of occurrence than the lower repetition categories.

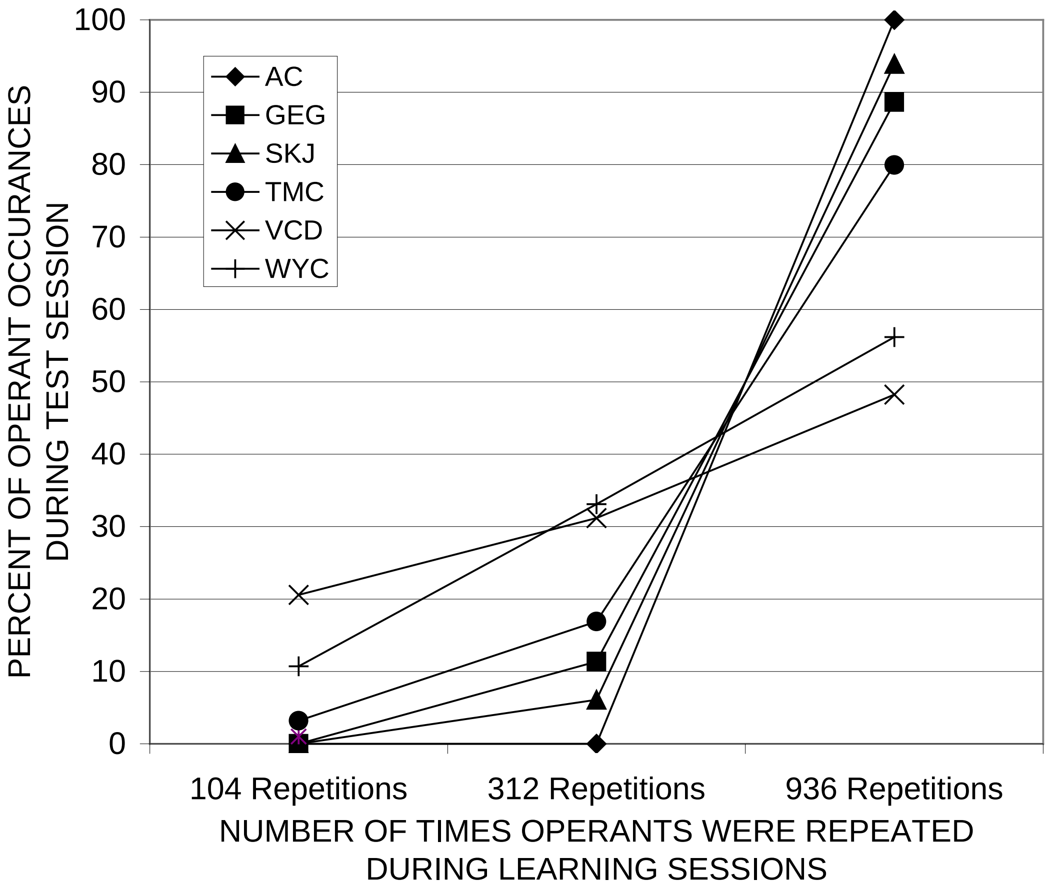

Figure 7. Frequency with which the three categories of operants occurred in the test session, as a function of number of times they were required to be repeated in the learning sessions, for six of the seven participants in Experiment 7. Here again, the three repetition categories were in a 1:3:9 ratio rather than the 1:2:4 ratio used in previous experiments. Again, for these six participants, the 936-repetition category showed a markedly higher frequency of occurrence than the lower repetition categories.

In addition, in Experiment 2 (also using a 1:3:9 ratio of prior repetitions, although spread out over a larger number of learning sessions), six of eight participants showed a slightly higher emission frequency for highest-repetition operants than lower-repetition ones during the test session [**Figure 8**].

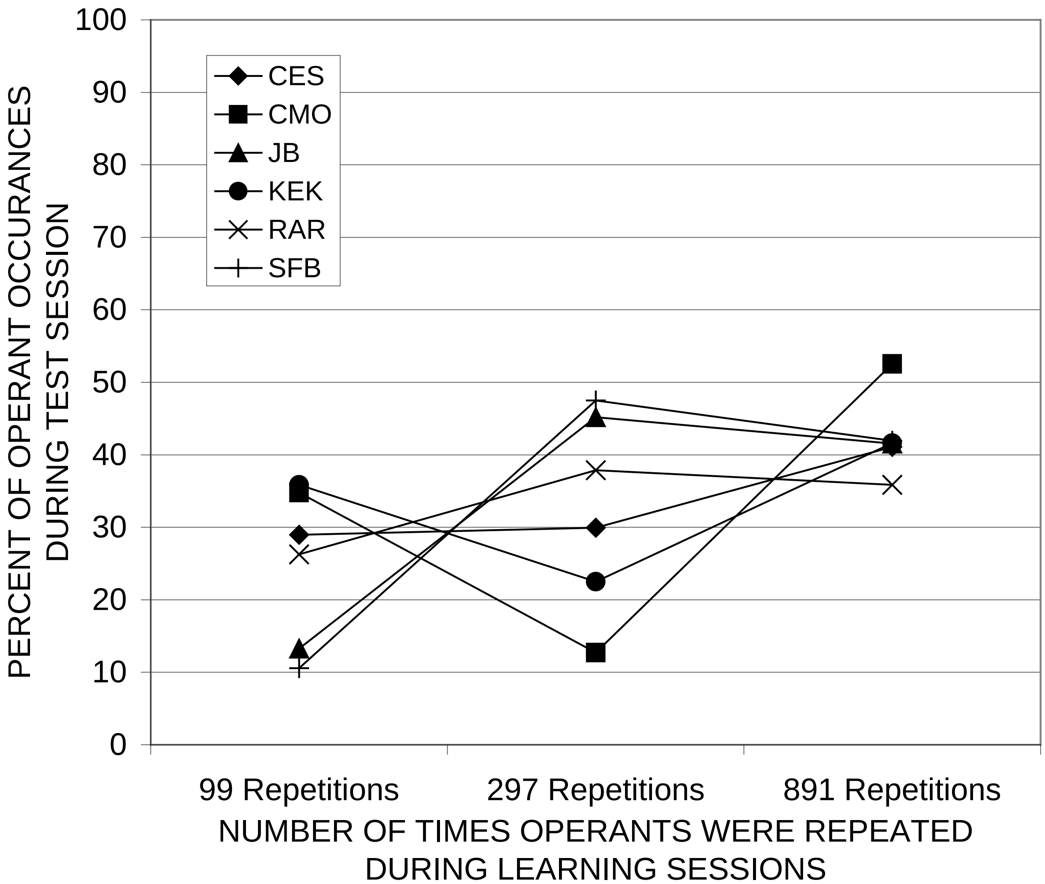

Figure 8. Frequency with which the three categories of operants occurred in the test session, as a function of number of times they were required to be repeated in the learning sessions, for six of the eight participants in Experiment 2. Here the three repetition categories were again in a 1:3:9 ratio rather than the 1:2:4 ratio used in previous experiments. The 891-repetition category showed a higher frequency of occurrence than the lower repetition categories.

Results from Experiment 4, which tested two different ratios of repetitions at three different absolute value levels (a total of six different conditions), show the effect described above most clearly. During the test session, when participants were required to choose between the operants that constituted the lower prior repetition levels (20/40/80, 60/120/240, 20/60/180, and 40/120/360), they showed no clear preference, and their responses varied wildly on an individual level [**Figure 9**].

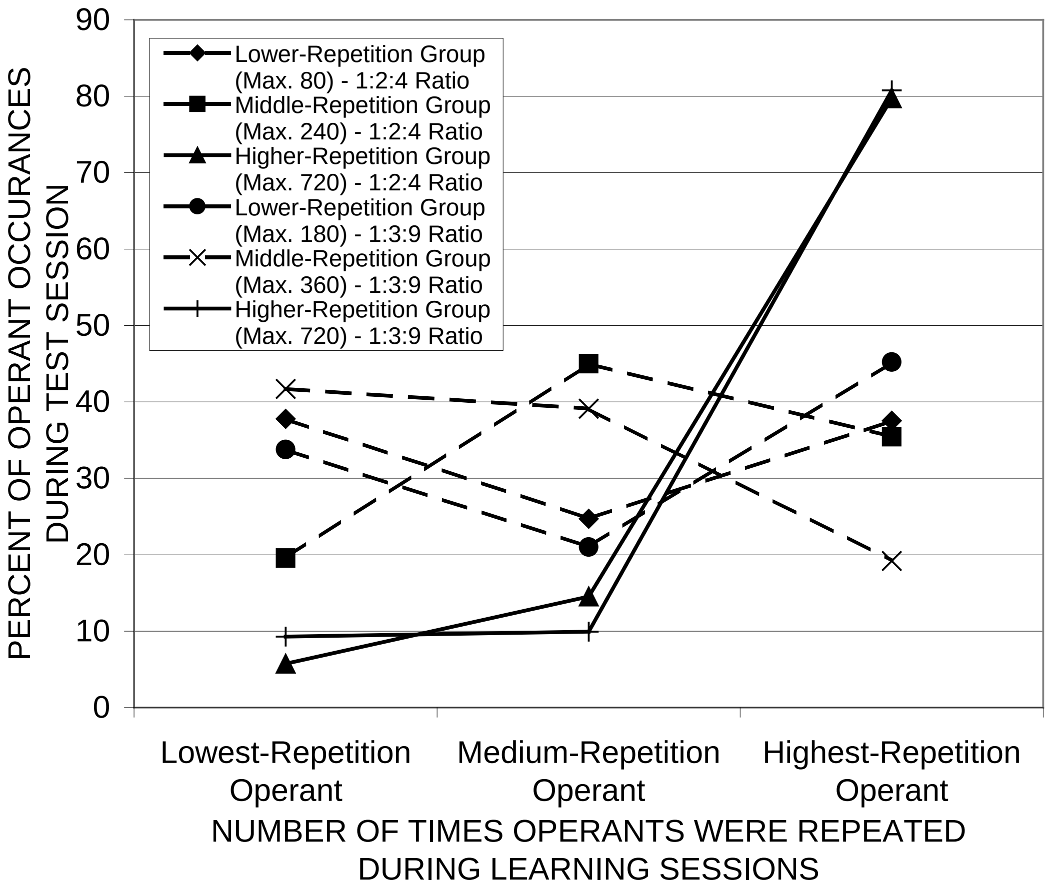

Figure 9. Frequency with which the operants constituting the two different ratios of learning session repetitions at three different absolute value levels (six conditions in all) occurred in the test session, averaged across all eight participants in Experiment 4. Only the 720-repetition operants show a consistent advantage.

But when choosing between the higher-repetition groups of operants (180/360/720 and 80/240/720 ratios), all participants showed an overwhelming preference for the highest-repetition operant, and four of seven participants typed the highest-repetition operant 100% of the time. The ratio of relative numbers of repetitions, whether 1:2:4 or 1:3:9, made no difference; the results for the higher absolute value group of operants from both ratios are almost identical.

This effect, when present, represents an advantage of highest-repetition operants over lowest-repetition ones. But the emission frequency of medium-repetition operants during the test session often showed considerable variability from individual to individual, in some studies more so than in others. Although all of the participants who showed the repetition effect discussed above chose highest-repetition operants more often than lowest-repetition ones (a generally increasing function), some of them chose medium-repetition operants more often even than highest-repetition ones (creating a function shaped like an inverted V), while others chose the medium-repetition operants less often than the lowest-repetition category (creating a V-shaped function). A third category of participants produced a monotonically increasing function in the test session, with the medium-repetition category chosen more often than the lowest-repetition one but less often than the highest-repetition one. Such individual variation regarding the use of medium-repetition operants is particularly noticeable in results from Experiments 2, 5, 6 and 9 [**See Figures 3, 4, 5, and 8**].

In none of the nine experiments discussed was there any statistically significant difference in the accuracy with which the different repetition-frequency categories of operants were emitted during the test session.

2. Resurgence of Noncriterial Operant Dimensions

Over the course of each participant’s learning sessions, all of the noncriterial keystrokes typed by that participant (the six or more discretionary keystrokes between the mandated first and last three letters of each operant) were grouped into three-letter patterns and tracked. Resurgence during the test session was measured by the “antiquity” of the three-letter noncriterial patterns emitted during that session. Antiquity is defined as the number of sessions in an individual participant's learning history one must count back to find a prior instance of that same pattern (actually, the average of the last three times the pattern was used). A higher average antiquity level thus represents a higher number of older noncriterial patterns, and constitutes resurgence within the behavior stream.

A high level of such resurgence was produced in this series of experiments by the imposition (during the final test session) of what one might term “stressors”—punishment of longer-than-usual pauses and of invalid operants, coupled with significant monetary reinforcement of valid operants. In general, the use of such “stressors” during the final session caused higher levels of resurgence, as measured by average antiquity of noncriterial patterns, than did extinction, which was used as the final session in an earlier series of experiments (not reported in this paper).

In addition, in the present series of experiments higher levels of noncriterial pattern antiquity were associated more strongly with invalid than with valid operants. (Note that noncriterial patterns themselves cannot be invalid, by definition. Operants are termed "invalid" only when the criterial requirements of the operant are not satisfied.) In all of the experiments, noncriterial patterns within invalid operants during the test session showed significantly higher average antiquity than those typed within valid operants. This effect was observed for invalid vs. valid operants during the participants' learning sessions as well, but was much more pronounced during the test session. Since this effect was seen in all experiments in this series regardless of individual differences in the learning sessions, and regardless of the relative emission frequency of a particular category of operant during the test session, it is shown only for Experiment 5, as representative of all the experiments [**Figure 10**].

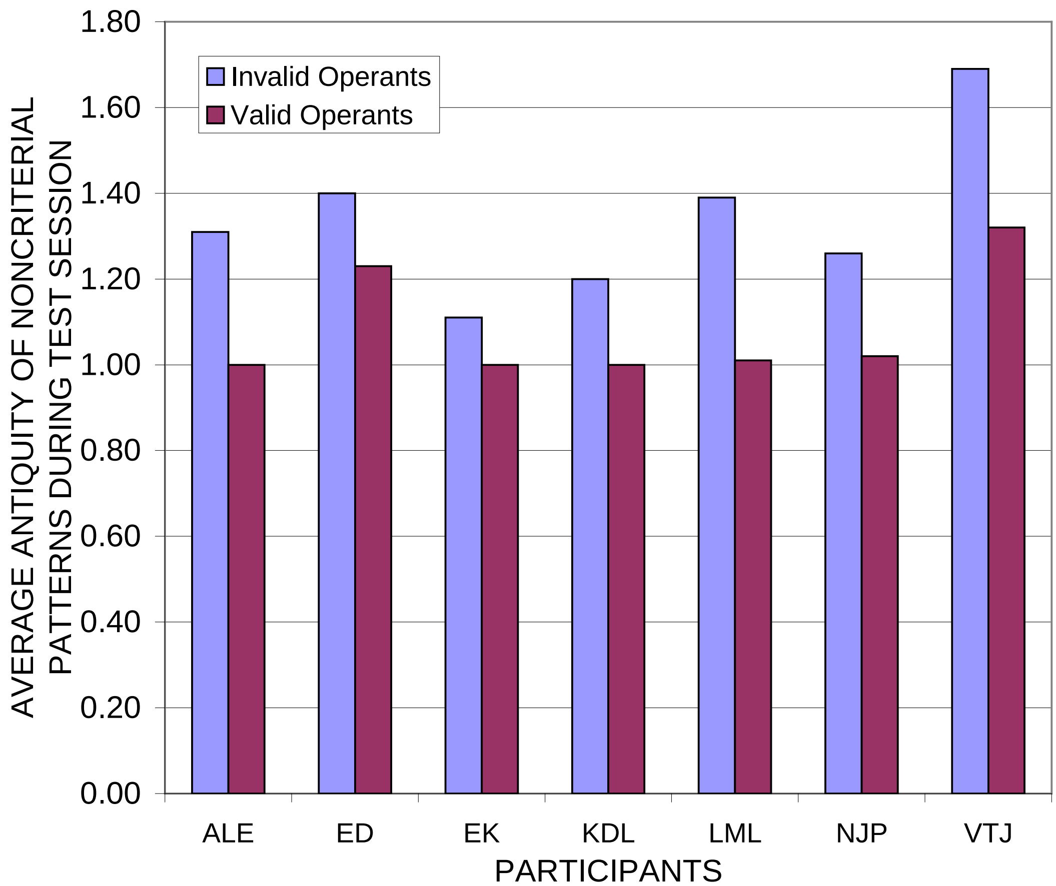

Figure 10. Comparison of average antiquity levels of noncriterial patterns (consisting of three-keystroke sequences) within valid and invalid operants emitted during the test session. The greater antiquity of patterns within invalid operants is seen in almost all participants, and was present in all experiments. The results for Experiment 5 are shown as representative of all the experiments.

Correlated with this increase in noncriterial pattern antiquity associated with invalid operants is the significantly higher percentage of brand-new noncriterial patterns (ones that have never previously appeared in that participant's history) observed in invalid operants, when compared with those that occur in valid operants [**Figure 11**].

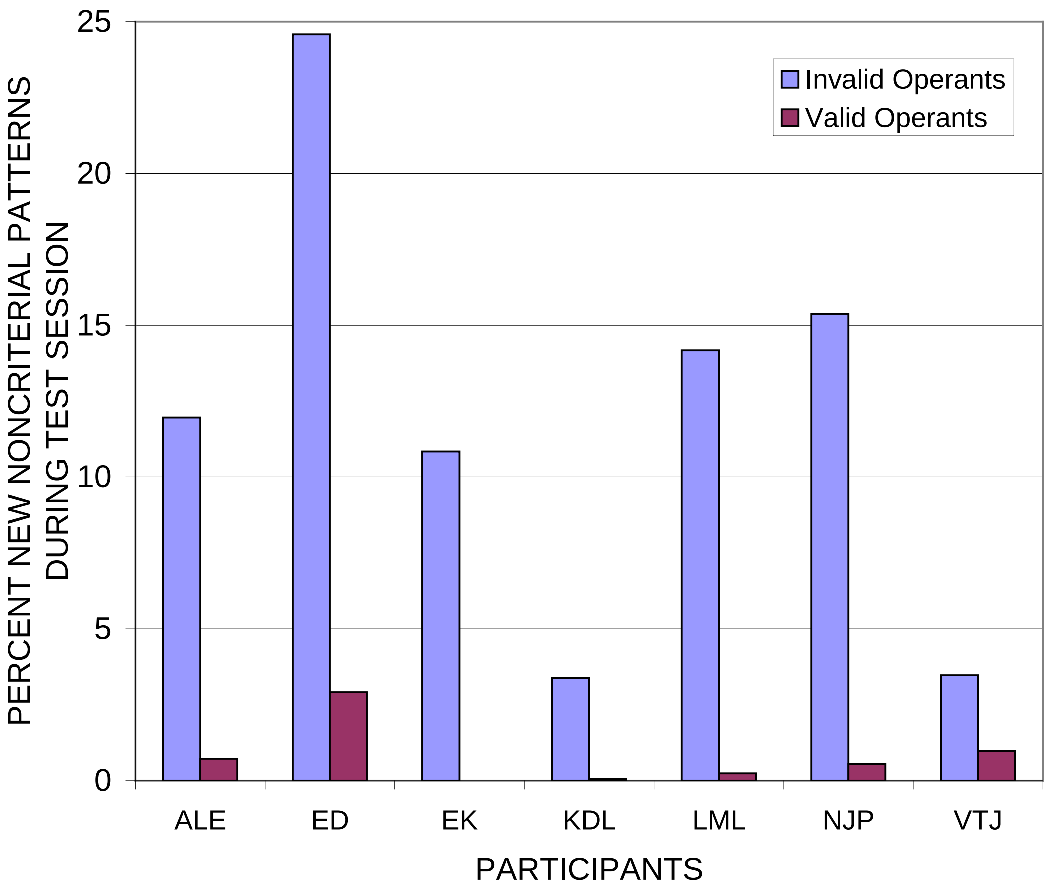

Figure 11. Comparison of percentages of brand new (never previously seen) noncriterial patterns within valid and invalid operants emitted during the test session. The higher percentage of new patterns within invalid operants is seen in almost all participants, and was present in all experiments. The results for Experiment 5 are shown as representative of all the experiments.

This too was seen in all experiments, and represents an additional increase over and above the increase in the number of new noncriterial patterns seen in the test session as a whole (when compared to the immediately preceding sessions). Again, the effect is shown only for Experiment 5, as representative of all the experiments.

It should be noted that the occurrence of greater numbers of both very old and brand-new noncriterial patterns in the test session is not merely the result of an increase in variability. Although participants do use a greater variety of noncriterial patterns during the test session than in previous sessions, they are still using only a very small fraction of the many thousands of possible three-letter patterns that could be formed using the twelve available letters.

In addition to the higher antiquity levels found in invalid operants, in certain experiments higher levels of noncriterial pattern antiquity during the test session were also associated with operants that had been required less often during the learning sessions (lowest-repetition operants). During the test session of Experiment 1, all seven participants showed higher antiquity levels for noncriterial patterns from lowest-repetition operants (whether valid or invalid) than for noncriterial patterns from other operants [**Figure 12**].

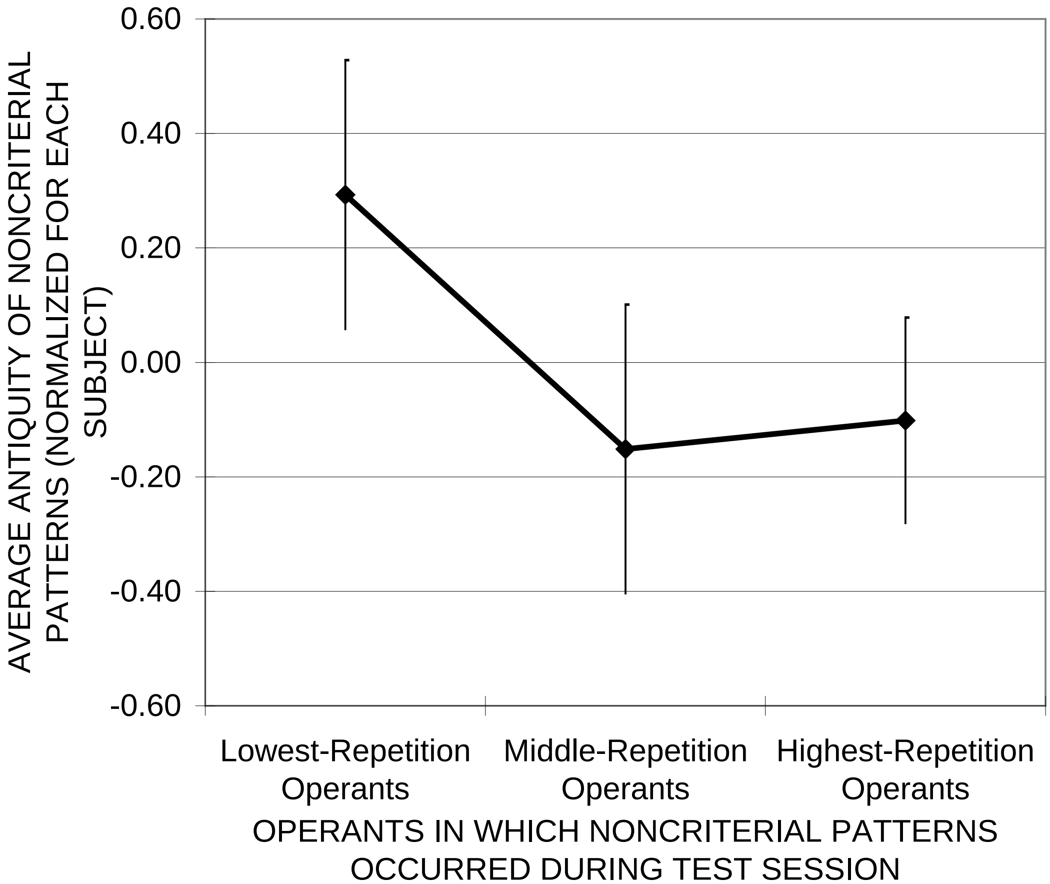

Figure 12. Comparison of average antiquity levels of noncriterial patterns within the three repetition categories of operants emitted during the test session, normalized for each participant by subtracting the value for each category from each participant's total session value, then averaged across all seven participants in Experiment 1.

This higher level of average noncriterial antiquity for lowest-repetition operants was, like the higher average antiquity level found in invalid operants, paralleled by an increase in levels of brand new noncriterial patterns for lowest-repetition operants.

DISCUSSION AND CONCLUSIONS

These experiments suggest that the criterial and noncriterial aspects of operants are affected in different ways by the imposition of certain contingencies and by certain history variables. Regarding the effects of number of prior repetitions on later occurrence, the results showed that operants that were required to be repeated more frequently during the learning sessions were emitted more often in the test session only when the absolute number of prior repetitions was high enough, regardless of the ratio of their number of repetitions to the number of repetitions for the less frequently required ones. These findings suggest that for this particular type of operant there may be a ‘threshold’ number of number of prior repetitions – in the range of 480 to 720 – that must be reached before the more highly-practiced operant gains any advantage. This idea is in line with prior literature, which indicates that the relationship between number of prior repetitions and later strength of an operant is rarely a simple one. Of course, the observed threshold figure of approximately 720 has no generality, and is doubtless specific to the type of operant and procedure used in these experiments. Simpler operants may have far lower repetition thresholds. The hopefully-general finding is that it is the absolute rather than the relative value of the number of repetitions that gives an operant an edge.

One possible explanation of this result is that the observed threshold represents the number of repetitions required to overcome participants’ individual idiosyncratic preferences for specific operants. Such preferences would also explain the large differences among participants in the emission frequency of the medium-repetition category: in four studies the number of repetitions for the highest-repetition operants was high enough to create almost universal preference for those operants over those in the lowest-repetition category, but since the number of repetitions for the medium-repetition category did not always reach that threshold, individual preference factors continued to prevail.

This finding raises the question of how these type of individual preferences are overcome by minimum numbers of repetitions. It may be related to findings in the motor program literature, which suggests an explanation based on the automatization phenomenon – that when certain behavioral sequences are repeated often enough, they become more "fluent" and less susceptible to the effects of other variables (Mechner, 1995; Mechner et al, 1997; Schneider, 1985).

The finding that the relationship between number of prior repetitions and later frequency of emission is usually not a simple monotonic function is also in line with the body of research exploring the relationship between the number of times a free operant was previously emitted and its subsequent resistance to extinction. In some of these studies (though not in others; as previously noted the literature is divided), higher levels of acquisition training generate a reduced number of responses in extinction, producing a function shaped like an inverted U, an effect often referred to in the literature as the overlearning (or overtraining) extinction effect (Traupmann & Porter, 1968, 1971; Tombaugh & St. Jean, 1972; Tombaugh, 1967; Barnes & Tombaugh, 1970; Carment & Miles, 1962; Wolach, 1970).

Although exposure to a stimulus is different from emission of an operant, it is sufficiently analogous to justify consideration of the relevant stimulus-exposure literature. Non-monotonic functions have often been obtained in studies that explore the effects of repeated exposure to a stimulus on later preference for or recall of that stimulus. In many studies of this type the relationship has been found to be highly complex (Hamid, 1973), and to depend on the precise methods and procedures used (Saegert & Jellison, 1970; Zajonc, Crandall, Kail & Swap, 1974). The finding in the current experiments, of a minimum number of prior repetitions needed to suppress individual differences among operants, can be compared to some of these results, although the non-monotonic repetition functions seen in the current studies are not uniform across participants.

The noncriterial aspects of the operants in the experiments presented show effects that are in some cases independent of, and in other cases affected by the variables applied to the criterial elements of the operants. The noncriterial elements often show resurgence. The “stressors” (such as monetary loss for incorrect operants, time pressure, or gain for correct operants) imposed during the test session caused resurgence of older noncriterial patterns, as measured by higher average antiquity levels. This finding raises the question of whether other conditions that might be termed stressful, such as fatigue, distraction, discomfort, or sudden increases in task difficulty would produce similar effects.

Resurgence, as measured by average noncriterial antiquity levels, was greater in invalid operants than in valid ones. This effect was always present to some degree, although most pronounced in the final test session, suggesting that errors in skilled performance may, in general, be associated with the resurgence of older behavior patterns. The increase in average antiquity levels was caused by a greater number of ‘spikes’, or individual noncriterial patterns with extremely high antiquity levels, rather than by slightly-higher noncriterial antiquity levels across the board. This finding is consistent with that of a recent experiment on variability which found that extinction produced very large increases in the numbers of formerly low-probability responses while leaving the overall probability hierarchy of responses unchanged (Neuringer, Kornell & Olufs, 2001).

In addition, the resurgence observed in invalid operants during the test session of the present experiments was always accompanied by greater numbers of novel (never-before-seen) noncriterial patterns. This finding is in line with experiments that have found that extinction not only increases variability but also increases the number of new responses (Neuringer et al, 2001).

Noncriterial resurgence during the final session was also higher for operants that had previously been practiced less often. This finding suggests that noncriterial and criterial aspects of an operant can become linked during the learning process. Prior studies have shown that levels of response variability, of which resurgence is a sub-set, often depend on noncriterial variables in the individual participant’s early learning history (Stokes, 1995; Stokes, Mechner & Balsam, 1999). Furthermore, in Antonitis’s 1951 study, successive cycles of conditioning and extinction caused increasing stereotypy, suggesting superstitious attribution of criterial status to noncriterial properties of the operant.

The present series of experiments demonstrates that under performance conditions the choice of operants and the characteristics of those operants, criterial as well as noncriterial, can be a function of the operants' frequency of repetition during learning, and history variables in general. The experiments also demonstrate a methodology, which uses revealed operants, that can be used to address other issues involving the characteristics of individual occurrences of operants.

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