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EFFECTS OF REINFORCER QUALITY ON BEHAVIORAL MOMENTUM: COORDINATED APPLIED AND BASIC RESEARCH

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The high-probability (high-*p*) instructional sequence has been an effective treatment for noncompliance. However, treatment failures have also been reported. We hypothesized that the efficacy of the high-*p* treatment may be improved by using higher quality reinforcers for compliance to high-*p* instructions. The resistance of compliance to change was tested by varying reinforcer quality in two applied studies and a basic laboratory experiment. Experiment 1 tested the hypothesis that an increase in reinforcer quality for high-*p* compliance will increase the effectiveness of the high-*p* treatment when it fails to increase compliance. Experiment 2 assessed the effects of reinforcer quality on resistance of compliance to change by presenting successive low-*p* requests following the high-*p* treatment. A basic laboratory study (Experiment 3) was conducted to further isolate the relation between reinforcer quality and behavioral momentum. Two different liquid reinforcers (sucrose and citric acid solutions) were presented in a two-component multiple variable-interval variable-interval schedule followed by a single extinction test session. Results of all three experiments showed a generally consistent relationship between reinforcer quality and behavioral momentum.

DESCRIPTORS: behavioral momentum, compliance, high-*p* treatment, integrated basic-applied research, noncompliance, reinforcer quality, resistance to change

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Two features of operant behavior are functionally related to rate of reinforcement: (a) response frequency and (b) the resistance of that frequency to change when opposed by procedures such as extinction, satiation, punishment, alternative reinforcement, and distraction. These two aspects of reinforced behavior have been the subject of over four decades of basic research that, in recent years, has also stimulated numerous applied studies.

Ferster and Skinner (1957) provided a comprehensive report of the orderly effects of reinforcement rate on response frequency using various single and compound schedules of reinforcement. Herrnstein (1961, 1970) later established that the frequency-determining effects of reinforcement rate for one behavior were relative to the reinforcement derived from other concurrently available sources. The quantitative expression of this functional relation, in the form of the matching law, provided an important experimental account of choice behavior. Potential applications of the matching law have since been the focus of several theoretical papers (e.g., Epling & Pierce, 1983; McDowell, 1982; Myerson & Hale, 1984) and clinical studies showing that human choice varies positively with relative reinforcement (Conger & Killeen, 1974; Mace, Neef, Shade, & Mauro, 1994; Martens & Houk, 1989; McDowell, 1981).

Similar connections between basic research and application have been established in the study of a behavior's resistance to change. The tendency for reinforced behavior to continue at a given rate, when opposed by operations such as extinction or

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punishment, has been shown in many basic studies to be a positive function of rate of reinforcement (e.g., Gollub & Urban, 1958; Nevin, 1974). Nevin, Mandel, and Atak (1983) represented this functional relation in an analogy between the momentum of objects in motion according to classical physics and the persistence of reinforced behavior. Their analysis considers response rate as analogous to velocity and the resistance of this response rate to change as the analogue of mass. Thus, procedures that increase or decrease a behavior's resistance to change (behavioral mass) or its frequency of occurrence (behavioral velocity) will have a corresponding effect on its momentum.

The behavioral momentum metaphor prompted Mace et al. (1988) to hypothesize that if a high rate of reinforcement were arranged for a high rate of compliance with instructions, compliance may persist when an individual is asked to do things that he or she ordinarily resists. Treatment consisted of presenting a rapid sequence of high-probability (high-*p*) instructions immediately preceding a low-probability (low-*p*) instruction with which the client was normally noncompliant. This article and several replications of the high-*p* treatment have shown that the intervention can increase compliance to clinically acceptable levels with individuals with normal development and individuals with mental retardation (Davis, Brady, Hamilton, McEvoy, & Williams, 1994; Davis, Brady, Williams, & Hamilton, 1992; Ducharme & Worling, 1994; Harchik & Putzier, 1990; Horner, Day, Sprague, O'Brien, & Heathfield, 1991; Houlihan, Jacobson, & Brandon, 1994; Mace & Belfiore, 1990; Singer, Singer, & Horner, 1987).

Although the studies cited above demonstrate the efficacy of the high-*p* treatment, there have also been reports of no or marginal improvement in compliance using this intervention (Rortvedt & Miltenberger, 1994; Zarcone, Iwata, Hughes, & Vollmer, 1993; Zarcone, Iwata, Mazaleski, & Smith, 1994). The impetus for the present experiments came from similar treatment failures with two noncompliant children admitted to our inpatient hospital unit for treatment of behavior disorders. Two sets of eight low-*p* instructions were identified for the 2 participants. Although the high-*p* intervention improved the overall percentage of compliance to moderate levels, it was effective with only five or six of the low-*p* instructions. When the high-*p* intervention has proven to be ineffective, alternative treatments have included guided compliance (Zarcone et al., 1993, 1994) and time-out (Rortvedt & Miltenberger, 1994). However, because these interventions can be contraindicated for highly aggressive clients, we turned again to the momentum metaphor for ideas to increase the effectiveness of the high-*p* treatment. The continuing development of applied behavior analysis may be enhanced through the application of the behavioral momentum metaphor to behavior-change interventions.

Nevin, Tota, Torquato, and Shull (1990) argued that Herrnstein's (1970) mathematical account of response frequency and Nevin's quantitative analysis of momentum are related to a unitary relative reinforcement account of operant behavior (see Nevin et al., 1990, pp. 374–378, for detailed development of this point). That is, response frequency and resistance to change are both measures of the strength of an operant and are functionally related to relative rate of reinforcement. Although response frequency is governed by operant contingencies (response–reinforcer relations) and resistance to change is governed by Pavlovian contingencies (stimulus–reinforcer relations; Nevin et al., 1990), both measures of response strength are diminished proportionally by factors that degrade relative reinforcement (e.g., extinction degrades the operant contingency that governs response frequency as well as the Pavlovian contingency that affects resistance to change). Conversely, operations that contribute to the value of relative reinforcement may strengthen response rate and resistance to change and, thus, may increase a behavior's momentum.

Because response frequency and resistance to change are influenced by a common factor, variables known to affect one may be hypothesized to affect the other. A number of laboratory studies using concurrent schedules of reinforcement have found that reinforcer quality can affect relative response frequency independent of rate of reinforcement. For example, nonhumans have shown a bias toward or preference for wheat over brain stimulation (Hollard & Davison, 1971), for wheat over buckwheat and hemp (Miller, 1976), and for higher concentrations of sucrose in liquid over lower concentrations or plain water (Heyman & Monaghan, 1994). Applied studies of choice using concurrent schedules have similarly demonstrated that behavioral allocation can be altered substantially by arranging qualitatively different reinforcers contingent on different response options (Neef, Mace, Shea, & Shade, 1992; Neef, Shade, & Miller, 1994).

The present study had three main goals addressed in three separate experiments. Experiment 1 tested the hypothesis that the compliance-increasing effects of the high-*p* treatment could be improved by reinforcing compliance to high-*p* instructions with a higher quality reinforcer (food vs. praise). Our assumption was that an increase in reinforcer quality would increase behavioral mass and result in a greater momentum of compliant behavior. In Experiment 2, we further tested the hypothesis that reinforcer quality affects the resistance of compliance to change by presenting successive low-*p* requests following the high-*p* treatment. A comparison of the high-*p* procedure using two qualitatively different reinforcers should show that relative resistance to change across successive low-*p* instructions is greater with the higher quality reinforcer. Finally, a basic laboratory study was performed to further isolate the functional relation between reinforcer quality and behavioral momentum. In Experiment 3, rats were trained to respond on a two-component multiple variable-interval (VI) VI schedule. One component of the multiple VI VI schedule arranged a sucrose solution and the other component used a citric solution as the reinforcer for VI responding. An extinction test for relative resistance to change was carried out across the two components. Our hypothesis was that behavior's resistance to change would be greater in the component associated with the higher quality reinforcer.

EXPERIMENT 1

Method

Participants and Setting

Two adolescent boys with moderate mental retardation participated in this experiment. Both had been hospitalized for treatment of noncompliance, severe aggression, and disruptive behaviors that were unmanageable at home and school. They had large physical statures that made interventions such as guided compliance impractical and dangerous. Bob was 14 years old and had several autistic characteristics including repetitive hand flicking and persistent preoccupation with smelling and spinning objects. He communicated with simple sentences and performed one- and two-step tasks. Rich was 16 years old and was diagnosed with autism. He received educational services at home due to pervasive noncompliance and aggression at school. Throughout the study, Rich received 50 mg of Mellaril®, 450 mg of lithium, and 375 mg of Depicote®, all taken three times per day. Rich spoke in simple sentences and could follow multistep instructions.

Compliance trials were conducted in a

Table 1
Mean Percentage Compliance to Low-*p* Instructions Across Conditions of Baseline (BL) and High-*p* Treatment with Praise (HwP), with Food (HwF), and with Praise plus Food (HwP+F)

Subject	Low-*p* instruction	(A) BL	(B) HwP	(A) BL	(B) HwP	(D) HwP+F	(C) HwF	(B) HwP	(C) HwF
Bob	1. Sit down	31	92	29	64				
	2. Wipe that up	23	100	29	91				
	3. Pick those up	38	85	57	91				
	4. Put that down	38	85	14	91				
	5. Clean that up	38	77	57	91				
	Mean 1 to 5	34	88	37	86				
	6. Come into the bathroom	15	23	29	17	69		29	83
	7. Come over here	23	15	14	0	31		14	67
	8. Stand up	23	54	14	17	77		43	67
	Mean 6 to 8	20	31	19	11	59		29	72
Rich	1. Wipe that up	20	80	17	94				
	2. Pick up the broom	0	100	17	94				
	3. Stand up	0	70	0	94				
	4. Go into the bathroom	20	90	17	91				
	5. Wipe off the table	0	100	17	89				
	6. Sit on the sofa	40	80	17	97				
	Mean 1 to 6	13	87	14	93				
	7. Sit at the table	0	10	0	0		92	35	92
	8. Write the letter A	0	10	0	0		50	15	92
	Mean 7 and 8	0	10	0	0		71	25	92

dormitory-style room (4.5 m by 6.0 m) equipped with a full bathroom, two beds, a table, four chairs, and a sofa during a portion of the experiment. An experimenter, one or two observers, and approximately one or two other children were present during the trials.

Response Definitions, Measurement, and Interobserver Agreement

The dependent measure for both participants was the cumulative frequency of compliance to low-*p* instructions. Low-*p* instructions were statements directed toward a subject by the experimenter that requested performance of a specific action. A prebaseline assessment showed that compliance to low-*p* instructions was ≤40% (Mace et al., 1988). Examples of low-*p* instructions were "Bob, stand up," "Come over here, Rich," and "Bob, wipe that up" (see Table 1 for specific low-*p* instructions). Compliance was defined as initiating the required response within 10 s of the instruction and completing it within 30 s.

The independent variable, the high-*p* treatment, was a sequence of high-*p* instructions presented prior to each low-*p* instruction. Compliance with high-*p* instructions was reinforced with praise, food, or both. High-*p* instructions were those that resulted in ≥90% compliance during a prebaseline assessment (Mace et al., 1988). Examples of high-*p* instructions were, "Bob, shake my hand," "Give me five, Rich," and "Bob, catch the ball." Mean compliance to all high-*p* instructions was 99.6% for Bob and 99.8% for Rich.

For each compliance trial, one or two trained observers independently recorded occurrences of high-*p* and low-*p* instructions, as well as compliance. Observers remained within 2 m to 5 m of the experimenter and the participant. Occurrence, nonoccurrence, and total agreement were calculated on a trial-by-trial basis by dividing the number of agreements by the number of agreements plus disagreements and multiplying by 100%. Agreement values were obtained on 46% of the trials for Bob and 58% for Rich, balanced evenly across low-*p* instructions and phases of the study. Interobserver agreement values for all dependent and independent variables were 98% or higher.

Procedures

Baseline. The experimenter stood within 1 m to 2 m of the participant, made eye contact, and issued a low-*p* instruction in a neutral tone of voice. Low-*p* instructions were selected randomly without replacement from a pool of eight. The interinstruction interval was approximately 60 s to 90 s. The consequence for compliance to low-*p* instructions was descriptive praise (e.g., "That's great, Bob. Thanks for wiping that up.").

*High-*p *treatment.* Procedures were identical to baseline except that each low-*p* instruction was preceded by a sequence of three or four high-*p* instructions. High-*p* instructions were selected randomly from a pool of 15 and were presented at 10-s intervals. The low-*p* instruction was delivered within 3 s to 5 s after compliance to the last high-*p* instruction in the sequence. The effectiveness of the high-*p* treatment was evaluated using three different reinforcers for compliance to each high-*p* instruction: (a) praise (e.g., "Good job giving me five!") on all eight low-*p* instructions for Bob and Rich; (b) food (small piece of cookie handed to the participant) on Instructions 6, 7, and 8 for Bob and on Instructions 7 and 8 for Rich; and (c) praise plus food on Instructions 6, 7, and 8 for Bob. Reinforcement of compliance to low-*p* instructions with descriptive praise remained unchanged across all high-*p* treatment conditions. Informal observations and anecdotal reports from parents suggested that Bob and Rich preferred food to praise.

Experimental Design

Effects of the high-*p* treatments on cumulative frequency of compliance to low-*p* instructions were evaluated with reversal designs replicated across low-*p* instructions, with phases represented by the following notation: A = baseline, B = high-*p* treatment with praise, C = high-*p* treatment with food, and D = high-*p* treatment with praise and food. Because the high-*p* treatment with praise (B) was effective for low-*p* Instructions 1 through 5 for Bob and Instructions 1 through 6 for Rich, an ABAB design was used for these low-*p* instructions. An ABABDBC design was used for Instructions 6, 7, and 8 for Bob. Instructions 7 and 8 for Rich were evaluated with an ABABCBC design.

Results and Discussion

Figures 1 through 4 depict the trial-by-trial cumulative frequency of compliance for each low-*p* instruction during the baseline and high-*p* treatment conditions for Bob and Rich. In Figures 1 and 3, the reinforcer for the high-*p* treatment consisted of praise only. In Figures 2 and 4, the reinforcer was praise, praise plus food, and food only in the designated treatment conditions. The mean percentages of compliance to low-*p* instructions by instruction and experimental condition are presented in Table 1. Compliance during the initial baseline was low for all low-*p* instructions for both participants. Low-*p* Instructions 1 through 5 for Bob (Figure 1) and Instructions 1 through 6 for Rich (Figure 3) were responsive to the high-*p* treatment with praise. These baseline and

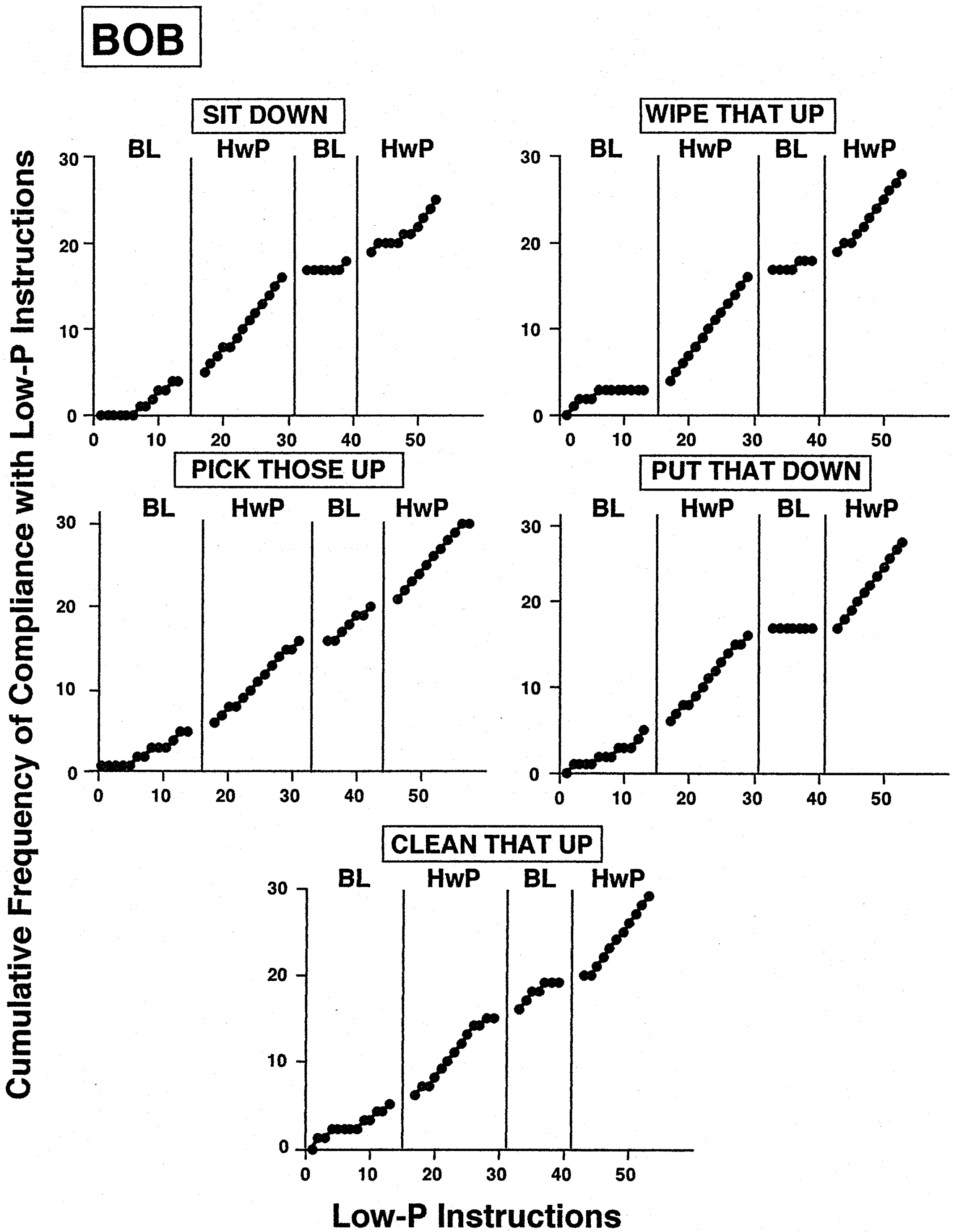

Figure 1. Trial-by-trial cumulative frequency of Bob's compliance to low-*p* instructions with and without high-*p* treatment with praise (HwP).

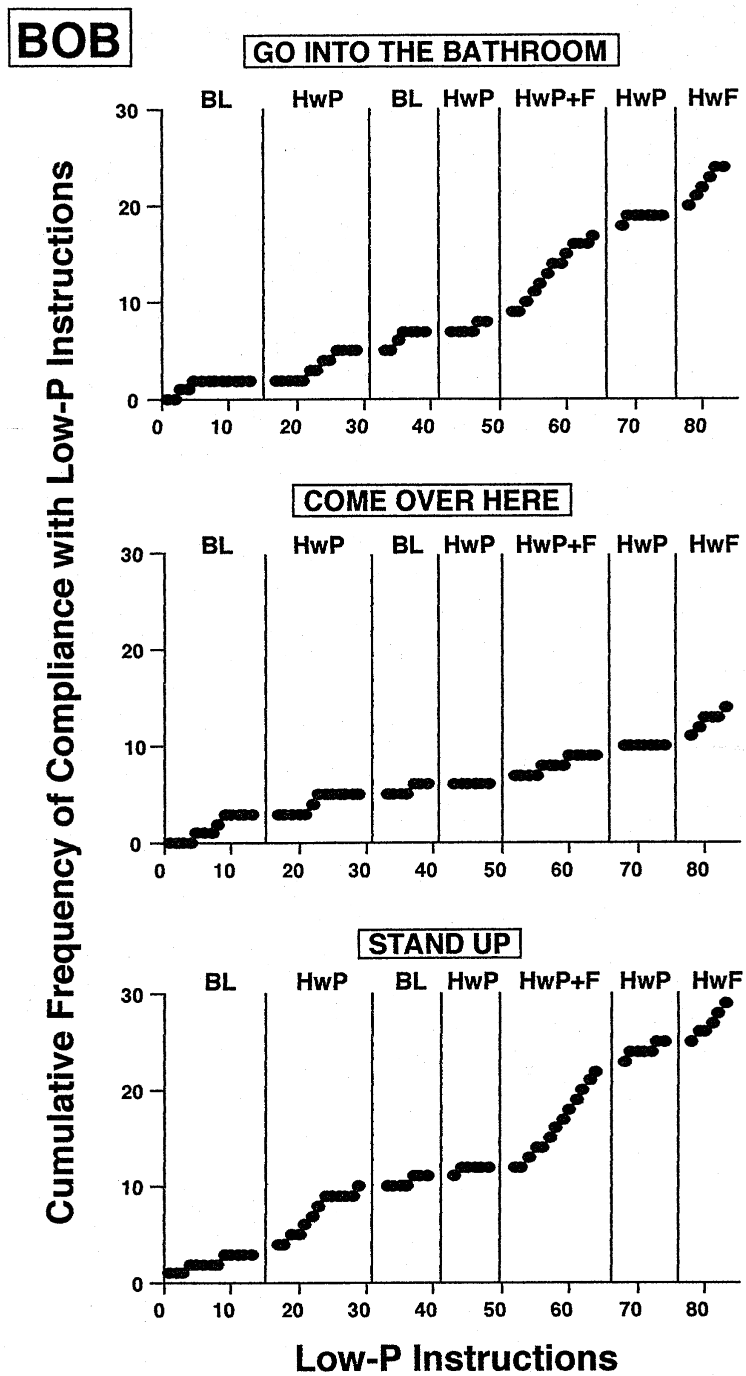

Figure 2. Trial-by-trial cumulative frequency of Bob's compliance to low-*p* instructions under baseline, high-*p* treatment with praise (HwP), high-*p* treatment with praise and food (HwP+F), and high-*p* treatment with food (HwF) conditions.

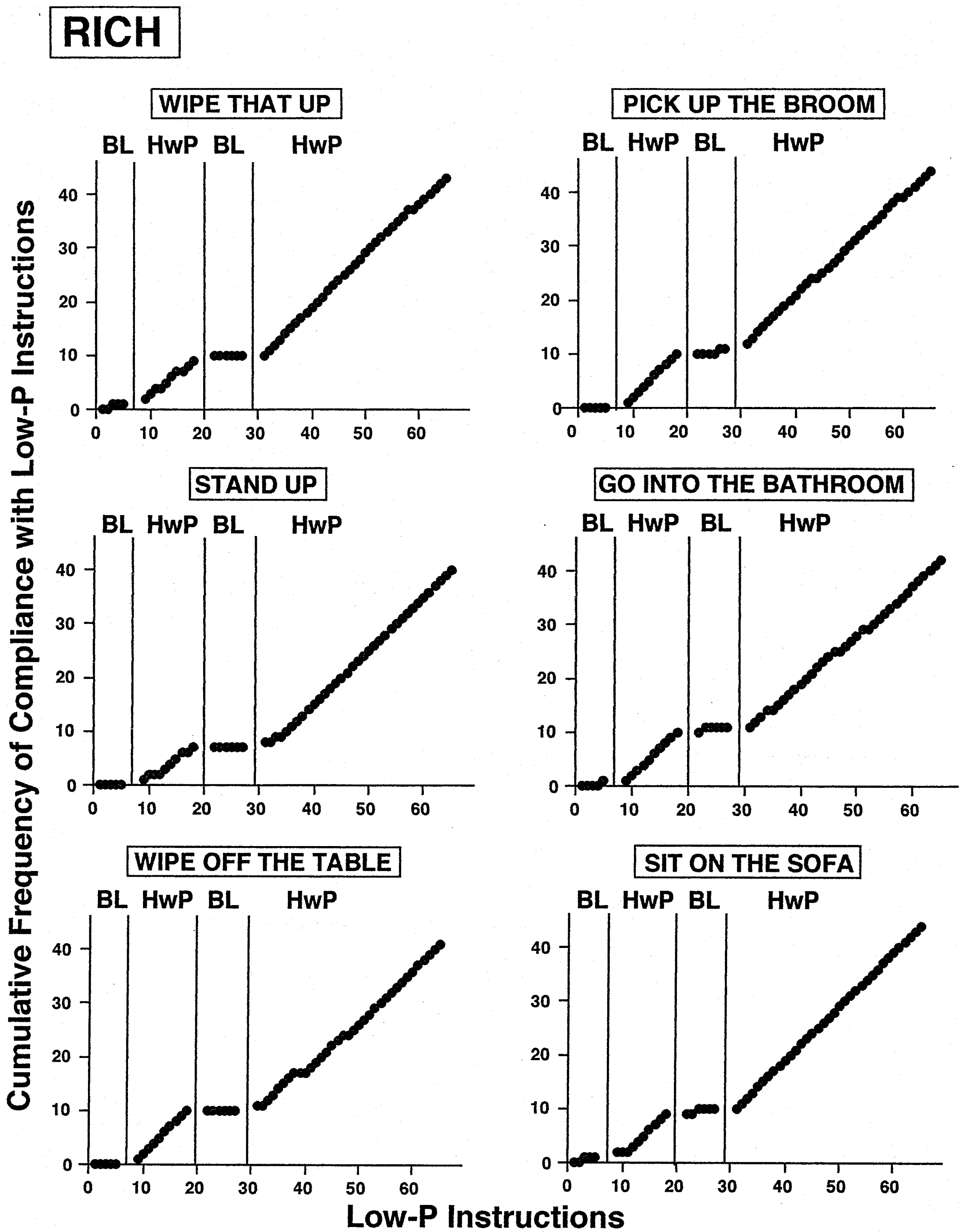

Figure 3. Trial-by-trial cumulative frequency of Rich's compliance to low-*p* instructions with and without high-*p* treatment with praise (HwP).

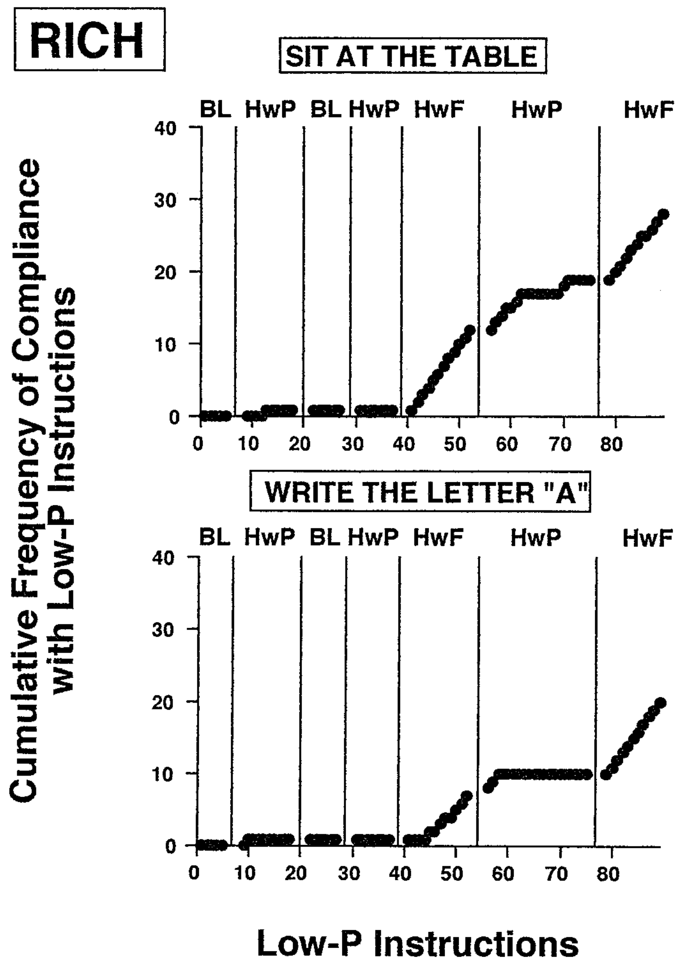

Figure 4. Trial-by-trial cumulative frequency of Rich's compliance to low-*p* instructions under baseline, high-*p* treatment with praise (HwP), and high-*p* treatment with food (HwF) conditions.

high-*p* treatment patterns of compliance were replicated in the third and fourth experimental phases for both participants.

In contrast, the high-*p* treatment with praise failed to improve compliance to Instructions 6, 7, and 8 for Bob (Figure 2) and Instructions 7 and 8 for Rich (Figure 4). However, reinforcing compliance to high-*p* instructions with praise and food sharply increased Bob's compliance to Instructions 6, 7, and 8. When food reinforcement was withdrawn from the treatment, compliance dropped again to baseline levels. Resuming food reinforcement for high-*p* compliance increased compliance to acceptable levels for each of these low-*p* instructions. For Rich, substituting food for praise contingent on high-*p* compliance produced an immediate increase in compliance for Instruction 7 and a delayed improvement for Instruction 8. Reversing to praise for high-*p* compliance again resulted in low levels of compliance. Replication of the high-*p* treatment with food only in the final phase produced very high levels of compliance for both instructions.

The results of Experiment 1 demonstrated that the efficacy of the high-*p* treatment can be improved by reinforcing compliance to high-*p* instructions with a presumably higher quality reinforcer than praise. In addition to this clinical finding, the results support the general hypothesis that behavioral momentum is functionally related to reinforcer quality. Experiment 2 examined this hypothesis further by comparing the effects of the high-*p* treatment with praise versus food on the resistance of compliance to change with repeated low-*p* instructions.

EXPERIMENT 2

Method

Subject and Setting

Rich (of Experiment 1) participated in this study. The setting for experimental sessions was identical to the first experiment. Rich continued to receive 50 mg of Mellaril® twice daily, 450 mg of lithium twice daily, and 375 mg of Depicote® twice daily for the duration of the study. Experiment 2 commenced 1 week following completion of the first experiment.

Response Definitions, Measurement, and Interobserver Agreement

The dependent measure was the percentage of compliance to low-*p* instructions. The same high-*p* instructions and five of the eight low-*p* instructions described in Experiment 1 were used. The two low-*p* instructions that were unresponsive to the high-*p* treatment with praise and the low-*p* instruction directing the participant to sit on a sofa were excluded (the sofa was no longer available).

Definitions and procedures used to measure occurrence and compliance to low-*p* and high-*p* instructions were identical to those in Experiment 1. A second independent observer collected interobserver agreement data on the above measures during 52% of the sessions representing all phases and conditions of the study. Mean occurrence, nonoccurrence, and total agreement for all measures, calculated as in the first experiment, were 98% or higher.

Procedures

Phase 1. The procedures employed in this phase were identical to the high-*p* treatment with food reinforcement in Experiment 1. Each low-*p* instruction was preceded by the high-*p* treatment and constituted a single trial.

Phases 2 and 4. Two forms of the high-*p* treatment were alternated during these phases: (a) high-*p* compliance reinforced with praise and (b) high-*p* compliance reinforced with food. For both forms of the high-*p* treatment, compliance to low-*p* instructions was reinforced with praise. Each high-*p* instruction sequence was followed by five different low-*p* instructions to define a single trial. Low-*p* instructions were presented in a randomized order during each trial. The interval between low-*p* instructions was 15 s to 20 s. There were five trials per session and a total of five sessions in each phase.

Phase 3. Procedures in this phase were identical to Phase 1 except that both forms of the high-*p* treatment (with praise and with food) were alternated across sessions.

Experimental Design

The four phases described above were presented in an ABAB reversal sequence. Five trials were conducted daily, each separated by 20 min of free time. For Phases 2, 3, and 4, the two high-*p* treatments (with praise and with food) alternated in a counterbalanced order across trials and sessions.

Results and Discussion

Figure 5 shows Rich's percentage of compliance to low-*p* instructions during the four phases of the study. The data for Phases 1 and 3 are expressed as percentage of compliance by session, calculated for five trials per session and presented across 10 and 4 sessions, respectively. In contrast, compliance during Phases 2 and 4 is expressed as the percentage of compliance to the *i*th low-*p* instruction (e.g., percentage of compliance

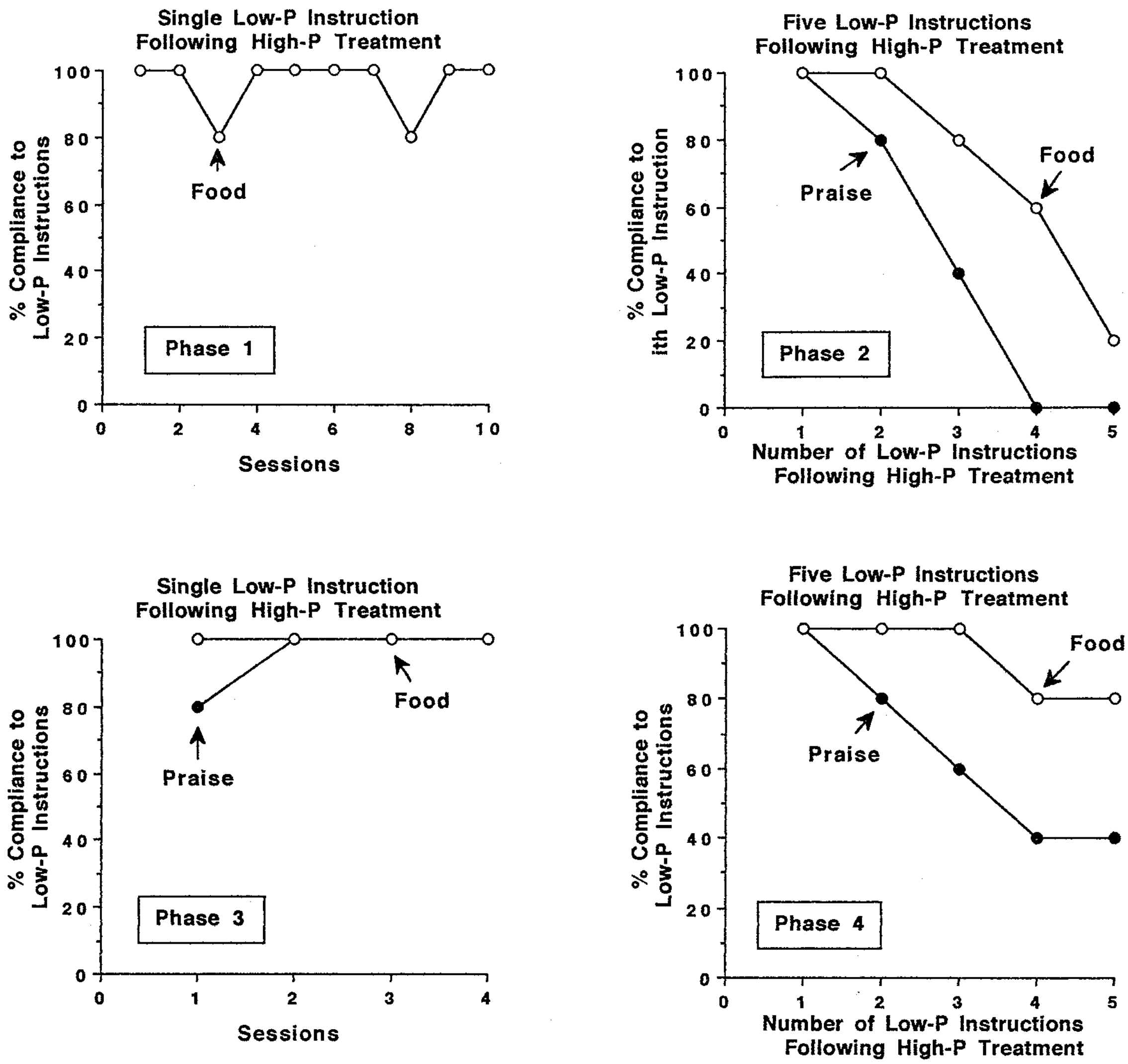

Figure 5. Phase 1: Percentage of compliance to low-*p* instructions by session using high-*p* treatment with food (five trials per session). Phases 2 and 4: Percentage of compliance to the *i*th low-*p* instruction in the sequence of low-*p* instructions using the high-*p* treatment with praise versus food. Phase 3: Percentage of compliance to low-*p* instructions by session using high-*p* treatment with food versus praise.

to all first low-*p* instructions, all second low-*p* instructions, etc.) in the sequence of five low-*p* instructions, collapsed across all sessions. In Phase 1, compliance to a single low-*p* instruction following the high-*p* treatment with food averaged 96.4%. During Phase 2, percentage compliance to low-*p* instructions decreased across successive low-*p* instructions. However, greater persistence in compliance occurred following the high-*p* treatment with food (M = 72%) than following the high-*p* treatment with praise (M = 44%). That is, the slope of the decrease in compliance was steeper with the high-*p* treatment with praise. Similar results were obtained during Phases 3 and 4. In Phase 3, percentage of compliance to a single low-*p* instruction following the high-*p* treatment was high with both forms of the intervention (with praise, M = 95%; with food, M

= 100%). Compliance in Phase 4 persisted more using the high-*p* treatment with food (M = 92%) than with praise (M = 64%).

Although the results of Experiments 1 and 2 suggested a general functional relation, conclusions about reinforcer quality and behavioral momentum remain tentative because prebaseline assessments of reinforcer preference were not conducted. Thus, value can only be inferred as the active variable because it was not directly assessed. In addition, on a conceptual level, important procedural differences exist between laboratory momentum studies and the high-*p* treatment used in these two experiments. For example, Nevin et al. (1983) conducted momentum tests of satiation and extinction with pigeons following a baseline two-component multiple schedule with different VI schedules of reinforcement operative. Thus, their basic research examined the persistence of free-operant steady-state behavior that was reinforced on VI schedules. In contrast, the high-*p* procedure involves brief bouts of signaled discrete-trial behavior that is reinforced on a fixed-ratio (FR) 1 reinforcement schedule. Because the behavioral processes involved in the high-*p* treatment have yet to be established, the differences between laboratory and clinical procedures preclude unequivocal interpretation of high-*p* treatment effects within a behavioral momentum framework. For these reasons, we turned to the nonhuman operant laboratory to provide a better experimental isolation of the general functional relation between reinforcer quality and behavior's resistance to change (i.e., behavioral momentum).

EXPERIMENT 3

Method

Subjects

Four experimentally naive male Charles River CD rats (MV-46 to MV-49) were housed individually and were maintained on a 23-hr water deprivation schedule by providing each animal 10-min access to water approximately 60 min after each session. Food was always available in each animal's home cage. The rats were 2 months old at the beginning of the experiment.

Apparatus

Two-bottle preference tests were performed in a modified Micro-BARRIER plastic rat cage (Allentown Caging) measuring 26.7 cm by 48.3 cm by 20.3 cm. Two graduated 70-ml plastic drinking bottles were centered on top of a wire bar lid, 7.9 cm apart, and their sipper tubes protruded 5.4 cm into the cage. The exterior of the cage was blackened, except for a small observation window.

Operant sessions were conducted in two BRS/LVE rat operant conditioning chambers with a left lever installed. This lever protruded 2.7 cm into the chamber from the right wall (operant panel) and required a minimum force of 0.13 N to operate. Constant or flickering (5 flicks per second; fps) visual stimuli were provided by a bank of three jewel lights located 4.3 cm above the lever. A Gerbrands water dipper provided 4-s access to 2 ml of either water, sucrose, or citric acid solution through an opening centered on the operant panel 1.2 cm above the grid floor.

The plastic cage was placed on a desk, and a small lamp provided room illumination during the two-bottle preference tests. The chambers were placed in MED Associates sound- and light-attenuating enclosures (Model ENV-015M). Sound attenuation during all sessions was provided by a Grason-Stadler white noise generator (Model 901B). A WYSE 80286 computer, using either BASIC or MED-PC notation, was used to program stimuli and record responses during taste preference and operant conditioning sessions.

Procedure

Two-bottle taste preference test. Ten daily sessions of a two-bottle taste preference test were conducted prior to the start of operant conditioning. The session length was 15 min, and the rats could drink freely from bottles filled with either 0.075% (weight/volume) sucrose or 0.075% (weight/volume) citric acid solutions. The assignment of sucrose and citric acid solution to either the left or right drinking bottle alternated across days for all subjects, and the occurrence of sucrose in the left or right bottle on the first day of testing was counterbalanced across pairs of subjects. The amount of sucrose and citric acid solutions (in milliliters) consumed each session was recorded.

Preliminary operant training. Two sessions of dipper training were conducted by allowing 4-s access to water according to a fixed-time 30-s schedule for a total of 30 reinforcers. The method of differential reinforcement of successive approximations (shaping) was then used to establish lever-press responding using 4-s access to water as the reinforcer. Shaping and 3 days of continuous water reinforcement were programmed on the left lever. The FR schedule was gradually increased to an FR 15 across several sessions. The FR training was followed by 20 sessions of a two-component multiple VI 60-s VI 60-s schedule of reinforcement. The reinforcer during this prebaseline condition was 4-s access to water in each of the two 6-min components.

Operant baseline and extinction test. Experimental sessions were conducted 5 days per week and consisted of four cycles of a two-component multiple schedule. Each component was 6 min in duration and was separated by a 1-min dark period with no programmed events. Each cycle lasted 14 min, and the total session length was 56 min. The ordering of components within a cycle was determined randomly without replacement.

The design involved a single alternation between a baseline and an extinction test condition. During the baseline condition, two independent VI 60-s reinforcement schedules were operative during Components 1 and 2 and were signaled by either a flickering (5 fps) or a continuous visual stimulus, respectively. The reinforcers were 4-s access to 0.075% (weight/volume) sucrose solution during Component 1 and 4-s access to 0.075% (weight/volume) citric acid solution in Component 2. The presentation of the qualitatively different solutions was accomplished by manually exchanging dipper trays during the dark periods between components. The dipper cups were cleared with a blast of compressed air between components. The amount of sucrose and citric acid solution consumed per session was recorded.

A single extinction test session followed the baseline condition and employed the same multiple schedule described in baseline, except that the liquid reinforcement was discontinued (the dipper was inoperative). The extinction session ended upon completion of the block in which the rat's elapsed time without a response on either lever exceeded 12 min (five cycles for each subject).

Results and Discussion

Taste Preference Tests

Figure 6 shows the amount of sucrose and citric acid solution consumed across each of the 10 sessions of the two-bottle taste preference test for all animals. Three (MV-46, MV-47, and MV-49) of the 4 subjects initially showed indifference in the consumption of the sucrose and citric acid solutions. All animals showed a substantial preference for sucrose by the end of the taste preference test, as indicated by the relatively greater amount of sucrose solution consumed.

Baseline

The average response rate, reinforcement rate, and amount consumed per session

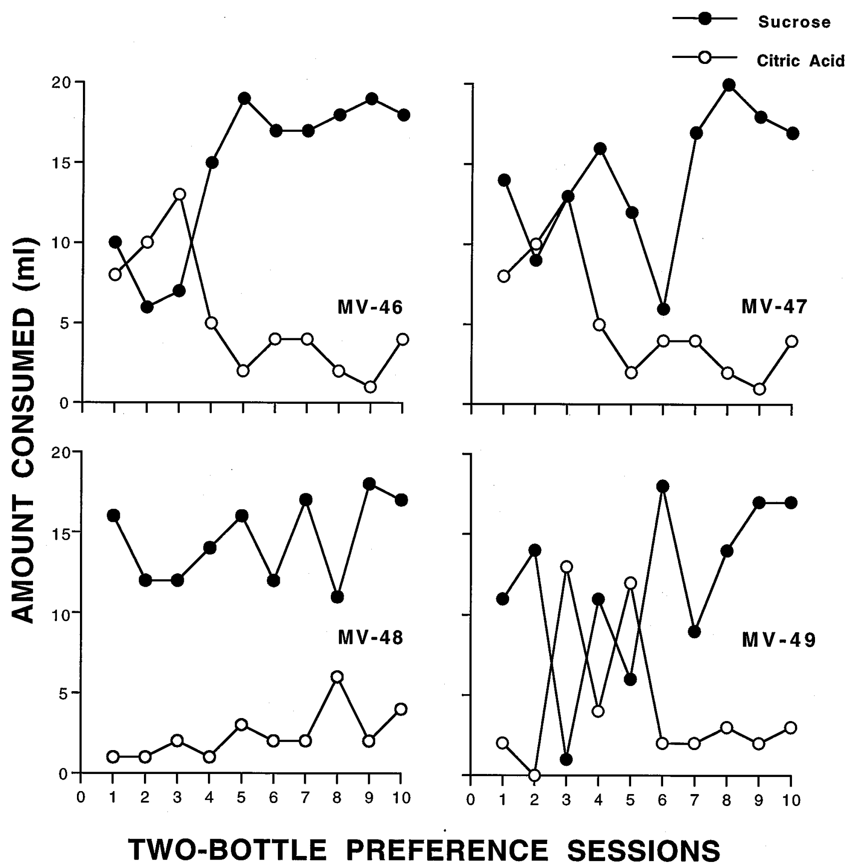

Figure 6. Amount (in milliliters) of sucrose and citric acid solution consumed across each of the 10 sessions of the two-bottle taste preference test for all animals.

across the two components during baseline are shown in Table 2. These data are the mean and standard error calculated over the last 3 days of baseline. The rats' response rates were comparable across the components providing sucrose and citric acid solutions as reinforcers. The absolute response rates differed for subjects. MV-46 and MV-47 showed high response rates, whereas MV-48 and MV-49 showed relatively lower rates of responding. In most cases, the obtained rates of sucrose and citric acid reinforcement were slightly less than the rates programmed by the VI 60-s reinforcement

Table 2
Responses per Minute, Reinforcers per Minute, and Amount Consumed (in Milliliters) per Session, Across the Sucrose and Citric Acid Components During Baseline for All Rats

	Response rate		Reinforcement rate		Amount consumed	
Rat	Sucrose	Citric acid	Sucrose	Citric acid	Sucrose	Citric acid
MV-46	20.14 (2.74)	22.66 (0.13)	0.99 (0.13)	0.86 (0.03)	5.43 (0.62)	4.83 (0.29)
MV-47	23.49 (1.61)	26.02 (1.13)	0.93 (0.03)	1.07 (0.10)	5.23 (0.03)	5.67 (0.35)
MV-48	5.11 (0.96)	6.02 (0.68)	0.93 (0.06)	0.89 (0.07)	4.87 (0.30)	4.93 (0.17)
MV-49	14.13 (1.32)	14.18 (0.52)	0.86 (0.03)	0.85 (0.01)	4.97 (0.03)	4.97 (0.32)

Note. Data entries are the means (with standard errors in parentheses) calculated across the last 3 days of baseline.

schedule (one reinforcer per minute). These data also show that the rates of sucrose and citric acid reinforcement were nearly equal across the two components. The amounts consumed are slightly inflated (~0.8 ml per session), probably because of the loss of solution when the dipper cups were cleared between components. Nevertheless, these data suggest that the rats consumed the total amount of the solutions delivered. Furthermore, the amount of sucrose and citric acid solution consumed was nearly equal across the two components.

Extinction Tests

The top portion of Figure 7 provides within-session measures of the differences in resistance to extinction across the two components for all subjects. These data are a proportion of the previous baseline response rates (mean of the last 3 days) as a function of cycles of the multiple schedule. The resistance to extinction was substantially greater for MV-46 and MV-47 during Component 1 (sucrose solution) than during Component 2 (citric acid solution). This effect was maintained across cycles of the multiple schedule for these subjects. Analysis of the within-session data for the remaining subjects showed little systematic differences in resistance to extinction between components.

The bottom portion of Figure 7 shows the difference in resistance to extinction across the two components during the entire extinction test session. These data are a proportion of the previous baseline response rates (mean of the last 3 days) based on extinction-session response rates for individual subjects (group data are also shown). All subjects showed relatively greater resistance to extinction during the component associated with the sucrose solution. This difference in resistance to change was most pronounced for MV-46 and MV-47. A Wilcoxon matched-pairs signed-rank test was performed on the group data and showed that the resistance to extinction was significantly greater for the sucrose component relative to the citric acid component ($z = -1.826$, $N = 4$, $p < .05$).

GENERAL DISCUSSION

These three experiments show a generally consistent relationship between reinforcer quality and behavioral momentum. In Experiment 1, food reinforcement for high-*p* compliance produced low-*p* compliance when the high-*p* treatment with praise only did not. Experiment 2 demonstrated that compliance to successive low-*p* instructions persisted more when food rather than praise was contingent on compliance to the high-*p* instructions. In the final experiment, the general functional relation between reinforcer quality and behavioral momentum was supported when the rats' proportion of baseline responding during extinction was greater in the multiple-schedule component using the preferred reinforcer. This series of applied and basic research experiments illustrates how coordinated research can stimulate advances in both behavioral technology and basic science that may not be pursued without deliberate consideration of developments in both sectors (Mace, 1991, 1994).

The high-*p* treatment initially reported by Mace et al. (1988) was developed because existing technologies had proven to be ineffective or were contraindicated for the large, aggressive clients who participated in the study. Nevin's (Nevin et al., 1983) analysis of behavioral momentum gave heuristic impetus to the design of a novel treatment for noncompliance that did not require physical contact with aggressive adults. A similar process occurred in Experiment 1. The usual high-*p* procedure (Mace et al., 1988) failed to improve compliance for some of the target low-*p* instructions for Bob

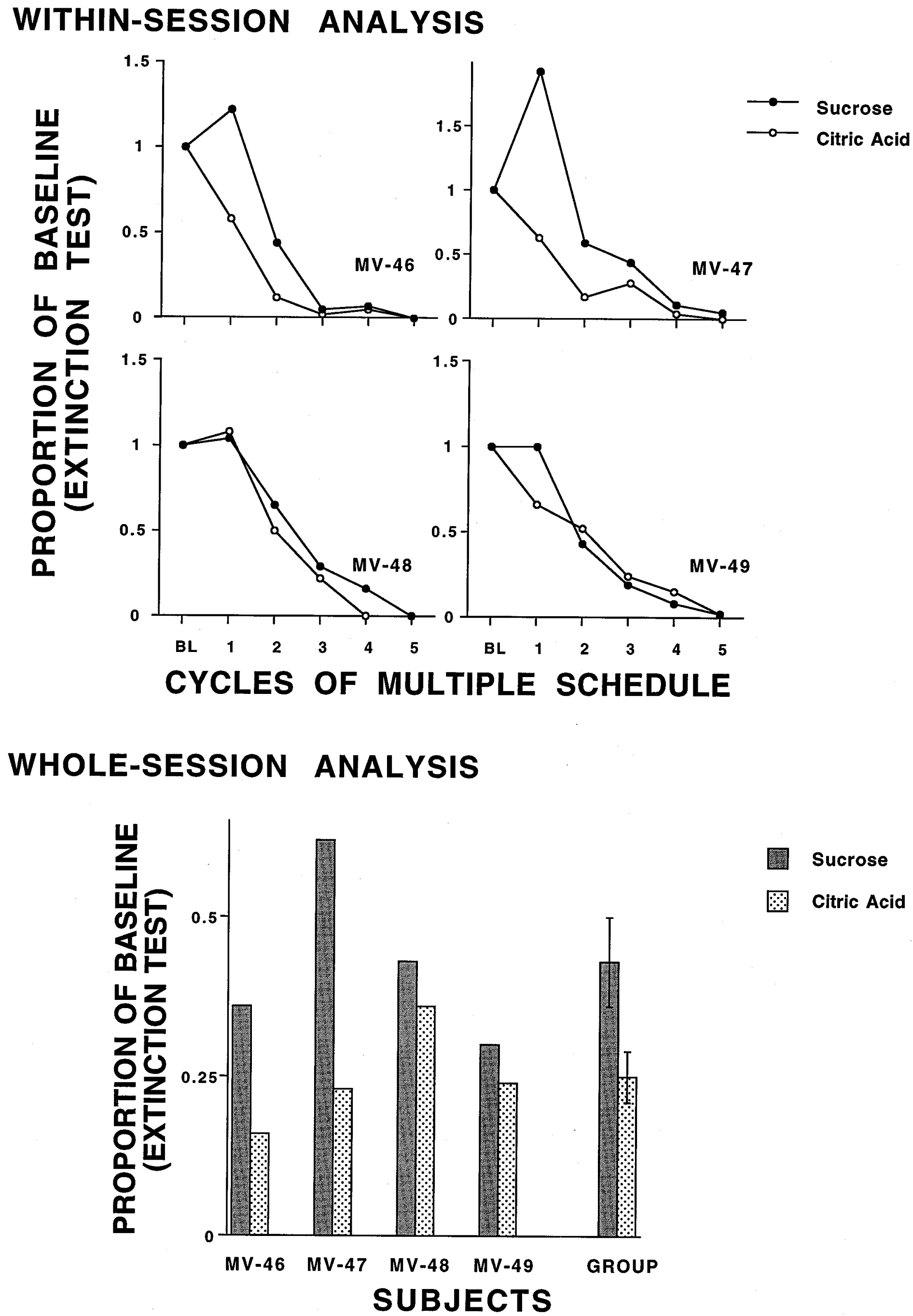

Figure 7. The upper portion shows within-session measures of resistance to extinction across cycles and components (sucrose vs. citric acid) of the multiple schedule expressed as proportion of the previous baseline response rates. The lower portion shows whole-session extinction test results (expressed as proportion of baseline responding) during citric acid and sucrose components for individual subjects and the group. Standard deviations for grouped data are represented by "I" bars.

and Rich. Considering the momentum metaphor, we speculated that the high-*p* treatment had established insufficient momentum to overcome the "oppositional force" of these particular low-*p* instructions. Initially, it appeared unlikely that we could increase the momentum of compliance; high-*p* instructions could not be delivered more quickly nor could reinforcement be supplied at a higher rate. That is, there appeared to be few avenues available to increase either behavioral mass or behavioral velocity. However, consideration of Nevin et al.'s (1990) relative reinforcement account of operant behavior suggested that reinforcer quality may influence momentum as it does choice.

The results of Experiment 1 illustrate the benefits that consideration of basic research findings can have on technology development. The effectiveness of the high-*p* treatment was enhanced by using a higher quality reinforcer for high-*p* compliance. However, secondary to the technological findings was the suggestion of a general functional relation between reinforcer quality and behavioral momentum. We first pursued this hypothesis with additional clinical research (e.g., Experiments 2 and 3; Mace et al., 1988). The purpose of Experiment 2 was to assess whether compliance with instructions would be more persistent when the high-*p* treatment used a relatively higher quality reinforcer. Following a baseline multiple-schedule procedure in which high-*p* compliance was alternately reinforced with praise in some sessions and food reinforcers in others, we opposed the compliance–reinforcer relation by presenting five successive low-*p* instructions at 15-s to 20-s intervals. This procedure was meant to parallel animal studies in which subjects are exposed to repeated cycles of an external variable such as extinction or satiation following a baseline multiple-schedule procedure (e.g., Nevin et al., 1983). The results were consistent with a general functional relation between reinforcer quality and behavioral momentum; that is, low-*p* compliance decayed less rapidly when high-*p* compliance was reinforced with food (Figure 3).

The experimental procedures employed with rats in Experiment 3 closely approximate those of Nevin et al. (1983) with pigeons and are similar to those used with rats by Cohen, Riley, and Weigle (1993), with the exception that the latter study involved fixed-interval (FI) and intermittent FR schedules. We held rate of reinforcement constant in both components of the multiple schedule (i.e., VI 60 s VI 60 s) and varied only the type of liquid reinforcer in each component (i.e., sucrose or citric acid solution). During a single extinction session comprised of five 14-min cycles of the two components, all 4 rats responded more in the component correlated with the reinforcer consumed more frequently in the prebaseline preference assessment. The within-session analysis of responding during extinction showed mixed results. Resistance to change during extinction was consistently greater in the sucrose component for 2 of the 4 rats (MV-46 and MV-47), with no systematic within-session differences apparent for the remaining 2 subjects. This disparity may be caused by a number of factors that future research should examine, including the concentrations of sucrose and citric acid solutions, component durations during baseline and extinction, and the qualitative differences between reinforcers (e.g., liquids vs. food pellets, food vs. brain stimulation). However, when the whole-session and within-session results are viewed collectively, the general functional relation between reinforcer quality and behavioral momentum appears to be supported. That is, behavior that is reinforced with a preferred reinforcer is more resistant to extinction than is behavior reinforced with a less preferred reinforcer.

Although Experiments 2 and 3 were not designed to elucidate the behavioral processes involved in high-*p* treatment effects, their results are generally consistent with a behavioral momentum account of the procedure. Despite differences in baseline procedure, both experiments found that responding persisted more in the situation correlated with the preferred reinforcer when the response–reinforcer relation was opposed by an external variable such as repeated low-*p* instructions or extinction. An alternative account of high-*p* treatment effects has been that high-rate reinforcement of instruction that closely precedes low-*p* instructions increases the probability that compliance will generalize to other stimuli in that general class (i.e., low-*p* instructions; Horner et al., 1991). However, Experiment 2 held constant the rate of reinforcement that was close to the sequence of five low-*p* instructions; the two experimental high-*p* conditions differed only in the quality of reinforcer for high-*p* compliance. Although it is plausible that reinforcer quality facilitates generalization in a manner similar to that proposed for reinforcement rate (Horner et al., 1991), the results of Experiment 3 suggest that reinforcement need not be proximal to momentum tests in order to observe increased behavioral persistence.

This series of experiments raises several questions for further research. First, more extensive study is needed of the relationship between reinforcer quality and behavioral momentum. Basic research should vary concentrations of sucrose and citric acid solutions parametrically to determine the shape of the functional relation as disparities in reinforcer quality vary. Investigations should extend to different types of reinforcers such as foods and sensory stimulation, with the possible development of hierarchies of momentum and reinforcer quality (see Miller, 1976, for the construction of hedonic scales for types of grain presented in concurrent reinforcement schedules). Applications of reinforcer quality to increase or decrease behavioral persistence should also be undertaken. For instance, the capacity of differential reinforcement of alternative behavior (DRA) to weaken the rate and resistance to change of aberrant behavior may vary with qualitatively different DRA reinforcers. Second, both basic and applied studies are needed to better clarify the behavioral processes involved in high-*p* treatment effects. Two possible approaches are to develop an animal model of noncompliance and the high-*p* treatment or to conduct highly controlled experiments with clinical cases. In either situation, the research strategy would be to alter the high-*p* treatment so as to manipulate variables that are known to affect momentum in multiple-schedule free-operant procedures. For example, noncontingent reinforcement could be added to the high-*p* sequence in a fixed-time (FT) schedule, yielding a high-*p* FT FR sequence, to increase the momentum of compliance (e.g., Nevin et al., 1990).

Beyond particular contributions to behavioral technology and science, we hope this study illustrates a viable approach to integration of basic and applied behavioral research. Our modification of the high-*p* treatment was directly influenced by consideration of the basic research literature on choice and Nevin's relative reinforcement account of operant behavior. In turn, identification of reinforcer quality as a variable that affects behavioral persistence in the laboratory emerged from the clinical need to improve the effectiveness of the high-*p* treatment. Both avenues became possible to pursue with the collaboration of basic and applied researchers.

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STUDY QUESTIONS

1. Describe the basic phenomenon that is usually described as behavioral momentum.
2. How has behavioral momentum typically been operationalized during compliance training, and what additional procedure was examined in this study?
3. How were high- and low-probability instructions established?
4. What conditions were examined in Experiment 1 and what results were obtained?
5. How did the measure of momentum differ from Experiment 1 to Experiment 2? Describe the results obtained in Experiment 2.
6. Describe the differences in arrangements in Experiments 1 and 2 compared to the way in which behavioral momentum typically is studied in the laboratory, which led the authors to conduct the third study.
7. Suggest a way in which Experiment 3 might have been conducted in an applied setting with the same participants from the first two experiments.
8. In Experiment 3, sucrose and citric acid were analogous to what components in Experiment 2? In what sense are they analogous?

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