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THE MOMENTUM OF COMPLIANCE

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Compliance with demanding requests that are normally ineffective may be increased by presenting a series of easy or high-probability (high-*p*) requests before the more demanding requests. Mace and his colleagues have discussed the effectiveness of the high-*p* procedure in relation to behavioral momentum—the tendency for behavior, once initiated and reinforced, to persist in the face of a challenge. The high-*p* procedure differs in several ways from that employed in laboratory research on momentum, and the methods and findings of basic research may not be relevant to applied work on compliance. This article reviews some laboratory procedures used in research on behavioral momentum, summarizes the major findings of that research, and discusses its relevance to the high-*p* procedure and its outcomes. Increased compliance with demanding requests following the high-*p* procedure can be understood in relation to the procedures and findings of basic research, but some questions arise in the process of translating research into application via the metaphor of momentum. These questions suggest some new directions for both experimental and applied behavior analysis.

DESCRIPTORS: behavioral momentum, response rate, resistance to change, compliance, high-*p* procedure

The metaphor of behavioral momentum gives us a way to talk about two independent dimensions of behavior that are of immediate concern to applied behavior analysis: the rate of responding that is established and maintained by the contingencies of reinforcement, and its resistance to change when responding is challenged or disrupted in some way. The metaphor identifies these two aspects of behavior with the velocity and mass of a moving body, respectively. The product of the velocity-like and mass-like dimensions of behavior is *behavioral momentum,* a compound dependent variable that captures the outcome of training conditions that influence response rate and its persistence when those conditions are altered.

The goals of applied behavior analysis include the establishment of desirable, adaptive behavior through interventions that also insure the persistence of that behavior when the intervention ends. Persistence requires that the behavior in question be sufficiently resistant to change so that it continues during the transition from treatment contingencies to the natural contingencies of everyday life. In terms of the momentum metaphor, a successful intervention endows the behavior in question with a high level of momentum. For example, an intervention designed to establish compliance with requests is successful if compliance occurs rapidly and reliably during training (high velocity) and persists effectively, after explicit training has been discontinued, in the classroom, workplace, and other social settings in which compliance is appropriate (high mass). However, if compliance deteriorated rapidly when the intervention ended (low mass), we would not be fully satisfied with the outcome regardless of the rate of compliance

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during the intervention. Conversely, if compliance occurred only infrequently during intervention (low velocity), we would not regard it as firmly established in the person's repertoire even if that low rate also occurred outside the intervention conditions. This latter observation might suggest that *non*compliance was highly resistant to change, perhaps because of an extensive history of reinforcement by escape from task demands. The therapist's problem is to overcome that history with interventions that establish a high rate of compliance during treatment and that make compliance likely to persist when treatment ends—in brief, to maximize the momentum of compliance.

This article begins by reviewing some laboratory research on behavioral momentum, conducted for the most part with pigeons as subjects, and summarizes its main findings, including their generality to people. It then discusses a procedure for establishing compliance in clinical settings that was developed by Mace et al. (1988), based in part on an extension of the momentum metaphor. Known as the high-probability (high-*p*) procedure, it differs from basic research on momentum in several ways, but its effectiveness can be understood within the context of that research.

A RESEARCH REVIEW

Methods and Measures

First, it is important to understand that momentum is a property of a *discriminated operant*—a three-term unit comprised of an antecedent or current stimulus situation, a specified response class, and the contingencies of reinforcement in that situation (Skinner, 1969). Interest focuses on the asymptotic response rate and the resistance to change of that response rate within that stimulus situation. Because the absolute value of resistance to change depends on the nature and value of the disrupter (e.g., amount of prefeeding or duration of extinction sessions), research has concentrated on resistance to change in a given stimulus situation relative to that in one or more other situations involving different reinforcement contingencies.

A particularly convenient experimental paradigm for evaluating the resistance to change of one discriminated operant relative to another is a multiple schedule of reinforcement, in which the experimenter presents two (or more) distinctive stimuli successively, in regular or irregular alternation, for predetermined durations. Different contingencies or schedules of reinforcement for a designated response (or responses) are arranged in the presence of these stimuli to define two (or more) discriminated operants, commonly termed the *components* of the multiple schedule. The components may be separated by time-out periods to minimize interaction between them. The component performances are trained until response rates appear to be stable to establish a reliable baseline, and then their relative resistance is evaluated by disrupting asymptotic performance in some way that applies equally to both components—for example, by prefeeding (giving access to food in the home cage shortly before an experimental session). The disrupter is usually arranged for a brief period (one or a few sessions) to minimize long-term effects of interaction between the disrupter and the baseline conditions of reinforcement. Resistance to change is measured most directly by comparing response rate under disruption with the immediately preceding baseline response rate, separately for each component. Equivalently, it may be estimated from the slope of a function relating response rate under disruption, on a logarithmic scale, to the value of the disrupter. The component performance that exhibits the smaller change relative to baseline, or the shallower slope, is judged to be the more resistant to change. Because comparisons are made within subjects and sessions, they are usually quite reliable.

An Experimental Example

Nevin, Tota, Torquato, and Shull (1990, Experiment 2) arranged a three-component multiple schedule that illustrates several of the major findings of research on behavioral momentum. They employed food-deprived pigeons as subjects in a two-key chamber. In one component (designated Component C in their article and signaled by lighting both keys white), a standard variable-interval (VI) 60-s schedule provided 60 food reinforcers per hour of time in that component for right-key pecks; left-key pecks were not reinforced. A second component (B, both keys lighted red) provided 15 reinforcers per hour for right-key pecks; again, left-key pecks were not reinforced. Thus, comparisons of baseline response rate and resistance to change for responding on the right key in Components B and C would evaluate the effects of different reinforcer rates for that response. A third component (A, both keys lighted green) arranged concurrent VI VI schedules that provided 15 reinforcers per hour for right-key pecks as in Component B and 45 reinforcers per hour for left-key pecks, providing a total of 60 reinforcers per hour as in Component C. Thus, comparisons of baseline response rate and resistance to change for responding on the right key in Components A and B would evaluate the effects of alternative reinforcement for the competing left-key response in Component A, and similar comparisons for Components A and C would evaluate the effects of the distribution of reinforcers across keys with a constant total. Components alternated irregularly with a time-out period between them. The paradigm is illustrated in Figure 1.

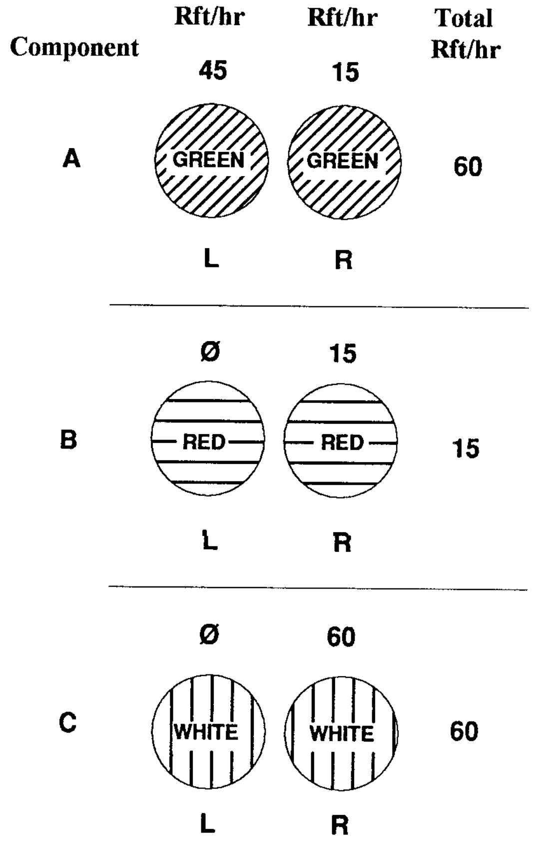

Figure 1. The three-component multiple-schedule paradigm employed in Experiment 2 of Nevin et al. (1990).

After response rates had stabilized, baseline performances were disrupted by allowing satiation in a long continuous session, by prefeeding in the home cage immediately before a session, and by extinction (i.e., termination of all reinforcers), with baseline recovery between disruptions. For all 3 subjects, right-key response rates in baseline were high in Component C, slightly lower in Component B, and substantially lower in Component A, reflecting the ordering of absolute reinforcer rate (60 per hour in C vs. 15 per hour in B) and relative reinforcer rate (1.0 in B vs. .25 in A) within components. However, right-key responding in Component A was substantially more resistant to change than in Component B. Likewise, right-key responding in Component C was more resistant than in Component B and was similar to that in Component A. These results are illustrated for extinction in Figure

2. Note especially that right-key response rate in Component B started above that in Component A and fell below it as extinction progressed. This pattern of results held for all birds and all three resistance tests.

The C-B comparison shows that resistance to change of right-key responding was directly related to the reinforcer rate for that response signaled by the component stimuli, consistent with a number of previous studies (see Nevin, 1992b, for review). However, the B-A and C-A comparisons suggest that resistance to change was directly related to the total reinforcer rate signaled by the component stimuli, independently of whether all reinforcers were contingent on the right-key response and independently of its baseline rate. Similar results were reported by Nevin et al. (1990, Experiment 1) using additional noncontingent reinforcers in one component rather than reinforcers that were explicitly contingent on a second alternative response as in Component A of Experiment 2. Nevin et al. (1990) concluded that the stimulus–reinforcer relation was the critical determiner of resistance to change. An important implication for applied work is that although alternative reinforcers (e.g., left-key reinforcers in Component A) reduce the rate of a target response, they also increase the resistance to change of that response rate because they are presented in the same stimulus situation (see discussion by Mace et al., 1990).

The Relativity of the Stimulus–Reinforcer Relation

The specification of the stimulus–reinforcer relation was refined by Nevin (1992a) in an experiment that arranged a constant reinforcer rate in one component of a two-component multiple schedule while the reinforcer rate in the alternated component was varied across successive conditions, with pigeons as subjects. Resistance to prefeeding and resistance to extinction in the constant component were inversely related to rein-

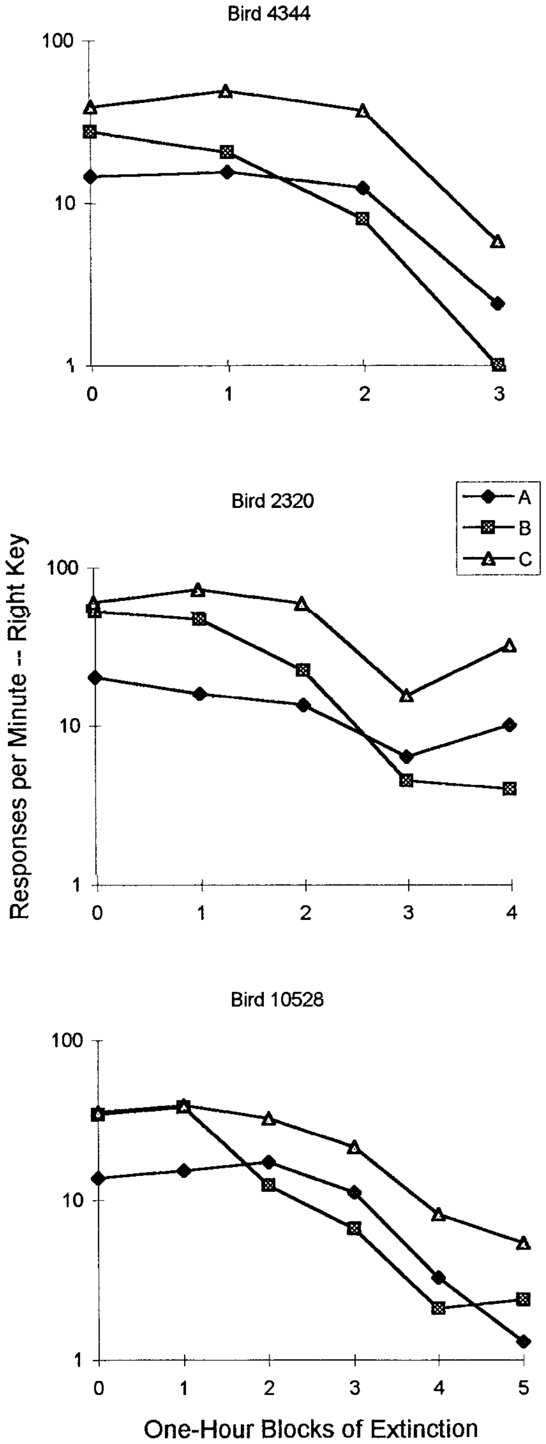

Figure 2. The course of responding on the right key in each of the three components of Experiment 2 of Nevin et al. (1990) during consecutive 1-hr blocks of extinction. Right-key response rates in the baseline session immediately preceding extinction are shown over 0, and the response-rate scale is logarithmic. Adapted from Nevin et al. (1990).

forcer rate in the alternated component. Nevin concluded that resistance to change depended on the relative rather than the absolute reinforcer rate in the presence of a stimulus, and Nevin (1992b) showed that a *contingency ratio* characterizing the reinforcer rate in a component relative to the overall average reinforcer rate in the experimental context accounted well for all of the resistance data obtained in his laboratory. For applied work, the implication is that resistance to change in the therapy setting depends on the reinforcer rate outside that setting as well as within it.

Generality to Other Species

Pigeons are notorious for pecking at lighted keys that are paired with food regardless of the response–reinforcer contingency, as shown in research on autoshaping (see Schwartz & Gamzu, 1977, for review). Thus, it is important both for interpretation and for applied analysis that pigeon data be replicable with humans who are engaged in arbitrary tasks. Experiment 1 by Nevin et al. (1990) has been replicated by Mace et al. (1990) with adults with mental retardation in a group home engaged in a sorting task, and by Cohen (1996) with college students engaged in a typing task. Experiment 2 has been replicated with rats by Mauro and Mace (1996), with visual but not with auditory stimuli. It has not yet been repeated with humans, to my knowledge, but the present status of cross-species replication suggests that the results reported by Nevin et al. (1990) do not depend on a species-specific propensity to direct responses at signals paired with reinforcers.

Summary and Conclusions

The following conclusions appear to be quite general:

1. The resistance to change of a discriminated operant depends directly on the rate of reinforcement obtained by the target response class.

2. The resistance to change of a discriminated operant maintained by a given rate of reinforcement increases if additional reinforcers are allocated to an alternative concurrent response, or are provided independently of responding.

3. The resistance to change of a discriminated operant maintained by a given rate of reinforcement is inversely related to the rate of reinforcement obtained by other, successive discriminated operants.

These three conclusions are consistent with determination of resistance to change by stimulus–reinforcer relations. Evidence reviewed by Nevin (1992b) suggests that these conclusions hold for reinforcer magnitude as well as reinforcer rate. His review also suggests that:

4. The resistance to change of a discriminated operant is independent of the steady-state baseline rate of the target response.

Taken together, these four conclusions comprise what has come to be known as behavioral momentum theory. In fact, they are not theoretical statements but are generalizations from experimental data, and as such are perpetually open to revision. Applied researchers may predict or interpret the effects of various interventions in relation to these conclusions, but should be careful to equate the relevant variables in applied settings with those that have been identified in basic research. A more rigorous and quantitative expression of these conclusions in relation to the metaphor of behavioral momentum is presented in the Appendix.

Some Qualifications

Harper and McLean (1992) challenged the generality of the foregoing conclusions in an experiment that varied the reinforcer rate equally in two multiple-schedule components with different reinforcer magnitudes. They found that variations in reinforcer rate produced equal proportional changes relative to baseline in the two components, a result that contrasted with their own finding (and several others; e.g., Nevin, 1974, Experiment 3) that responding was more resistant to change in the component with the larger reinforcer when free food was given during time-out periods between components. Accordingly, they distinguished between external disrupters such as intercomponent food or prefeeding that leave the component contingencies intact, and internal disrupters such as schedule changes that alter those contingencies, where the latter may not reliably confirm Conclusion 1. However, a change in the schedule for a large reinforcer may be a greater disrupter than a comparable change for a small reinforcer, as shown by Harper (1996). This difference might counteract the expected difference in resistance to change. Moreover, the usual effects of extinction (an internal disrupter) on multiple-schedule performances are entirely in accord with those of external disruptors (e.g., Shettleworth & Nevin, 1965). Complete characterization and scaling of effective disrupters remain to be achieved.

Cohen, Riley, and Weigle (1993) also challenged the generality of the foregoing conclusions by showing that resistance to change does not depend on the reinforcer rate for single-schedule performances that were trained and maintained for a number of consecutive sessions. For example, they found that resistance to prefeeding on fixed-ratio (FR) 40 did not differ from that on FR 160, regardless of the order of exposure to these single schedules. This result is contrary to the expectation that resistance to change is positively related to reinforcer rate, which was higher for the FR 40 performance. When they arranged the same schedules as components of a multiple schedule, however, they confirmed Conclusion 1, with one exception: When free food was provided during (not between) components (an internal disrupter) there was no systematic difference in the resistance of component performances with different reinforcer rates. These findings, which held for both rats and pigeons, suggest that the relation between resistance to change and baseline reinforcer rate may depend on the use of two or more signaled schedules that alternate within sessions. However, some single-schedule results exhibit a positive relation between resistance to change and reinforcer rate (for review, see Nevin, 1979, 1988), and the critical factors that distinguish single-schedule studies that confirm and disconfirm the positive relation remain to be identified.

Finally, different contingencies between responding and reinforcement in two components that establish different response rates may influence resistance to change even when stimulus–reinforcer relations are the same. For example, Lattal (1989) arranged a tandem FR VI schedule in one component and a tandem differential-reinforcement-of-low-rate (DRL) VI schedule in a second component with pigeons as subjects. He found that the low-rate tandem DRL performance was more resistant to disruption by free food between components than was the high-rate tandem FR performance, relative to their baselines, even though reinforcer rates were equated. Lattal's findings suggest that different sorts of contingencies may establish behavioral classes that are differentially susceptible to disruption. For example, disruption of DRL performance may lower the tendency to refrain from responding immediately after a response as well as the overall tendency to engage in the DRL performance itself, resulting in a smaller net reduction in responding. However, when comparable response classes are established in both components, as in multiple VI VI schedules, there is no correlation between response rate and resistance to change.

THE HIGH-*P* PROCEDURE AND COMPLIANCE WITH REQUESTS

An Example of the Procedure and Results

Mace et al. (1988) invoked the metaphor of behavioral momentum in relation to a method for increasing compliance with requests in adults with mental retardation who lived in a group home. Their procedure was designed to enhance compliance with requests such as "clear the table" or "take a shower," which were termed low-*p* requests because the clients rarely complied with them. To enhance low-*p* compliance, Mace et al. presented a series of three high-*p* requests with which the clients readily complied and appeared to enjoy doing, such as "give me five" or "show me your pipe," and then presented a low-*p* request. When the low-*p* request followed shortly after the high-*p* series, there was a striking increase in the probability of or a decrease in the latency to low-*p* compliance.

Compliance is a discriminated operant, in which the immediate stimulus is a request, the response class is an action that conforms to the request, and the consequence is at least intermittent social reinforcement, which is correlated with the overall stimulus situation in which compliance occurs. Accordingly, the findings of research on the momentum of discriminated operant behavior should be relevant. In the terms of the momentum metaphor, the high-*p* series may be viewed as establishing a high velocity of the response class "compliance." At the same time, reinforcers for compliance during the high-*p* sequence, whether explicit or implicit, increase the mass-like aspect of compliance. The resulting momentum serves to make compliance more resistant to the challenge of a low-*p* request.

The high-*p* procedure may not always be sufficient to enhance compliance. For example, Zarcone, Iwata, Mazaleski, and Smith (1994) failed to obtain enhanced compliance using this procedure with children who engaged in self-injurious behavior (SIB) unless it was coupled with extinction of SIB, possibly because SIB disrupted compliance during the high-*p* sequence. Conversely, the high-*p* procedure may not be necessary to enhance compliance. Carr, Newsom, and Binkoff (1976) observed a substantial improvement in compliance (and a reduction of SIB, which was their principal concern) when they told amusing stories to a child with mental retardation in the compliance-request setting. However, the high-*p* procedure has been used successfully with different clients in a variety of settings (e.g., Davis, Brady, Hamilton, McEvoy, & Williams, 1994; Davis, Brady, Williams, & Hamilton, 1992; Ducharme & Worling, 1994), and it is unquestionably a valuable addition to the repertoire of behavioral interventions for addressing problems of noncompliance. The issue here is the interpretation of the high-*p* procedure in relation to behavioral momentum.

Some Procedural Issues

The high-*p* procedure differs in a number of ways from the procedures that are employed in basic research. First, although there is a well-defined stimulus situation—the physical setting and the presence of the therapist—there is no well-defined alternated situation with different conditions of reinforcement that is analogous to an alternated component of a multiple schedule. Second, there is no steady-state baseline response rate against which to evaluate the effect of a disrupter, for two reasons: (a) The compliance response class is not a free operant, but is prompted by a discrete request and indeed is defined by correspondence between the request and the action; and (b) the high-*p* sequence is too brief to establish a reliable baseline. Third, the disrupter involves the presentation of a more demanding request rather than an orthogonal variable that is independent of the contingencies that maintain compliance. Collectively, these differences may seem to rule out the application of principles based on the disruption of free-operant behavior in multiple schedules. I will consider these differences in order.

The single-stimulus situation. As noted previously, Cohen et al. (1993) showed that alternated exposure to two or more schedule components that involve different schedules of reinforcement within a fairly short period, such as an experimental session, may be necessary for demonstrating a positive relation between resistance to change and rate of reinforcement. Thus, there may not be a positive relation between low-*p* compliance and the contingencies arranged by the high-*p* procedure within the single-stimulus situation of a therapy session. However, it is surely the case that a client experiences other stimulus situations and their correlated reinforcement contingencies for compliance, or noncompliance, or unrelated behavior, in the course of daily life. These situations and the uncontrolled or extraneous reinforcers available within them constitute the conditions that alternate successively with therapy sessions. The additional reinforcers arranged during therapy sessions by the high-*p* procedure could be effective in differentially enhancing the persistence of compliance within that setting, construed as one component of a client's life.

Response measures. Because compliance is by definition a response to a request, its rate of occurrence cannot exceed the rate of requests. Accordingly, its velocity-like aspect must be evaluated by its latency from the request, or its probability of occurrence within a brief period after a request. By contrast, virtually all research on resistance to change has employed the rate of a free operant as its dependent variable. I am aware of only two published exceptions. Fath, Fields, Malott, and Grossett (1983) measured both latency to the first response and response rate in each component of a multiple schedule and found similar changes in these measures when responding was disrupted. Elsmore (1971) showed that the probability of completing a fixed ratio within a brief trial period decreased to a lesser extent on trials that signaled a high probability of reinforcement than on trials that signaled a low probability of reinforcement when the ratio value was abruptly increased. This result parallels the usual finding that resistance to change is directly related to reinforcer rate in a component, suggesting that probability of responding in a discrete signaled period may be functionally similar to response rate. Thus, there is no reason to question the relevance of momentum research on the basis of the measures used in the high-*p* procedure. Moreover, Elsmore's disrupter (an abrupt increase in the response requirement) may be analogous to a low-*p* request.

The need for a stable baseline. Basic research on behavioral momentum has routinely established stable baseline response rates before evaluating resistance to change. In this way, it combines the interest in steady-state performance that characterizes modern research on operant behavior with a more traditional emphasis on behavior in transition during acquisition or extinction. Although a steady-state baseline is necessary for quantitative analyses (see the Appendix), it is possible to make ordinal comparisons of resistance to change without a stable baseline response rate. For example, Furomoto (1971) explored the effects of number of reinforcers on resistance to extinction in a parametric between-group experiment with pigeons as subjects. One of her groups received a reinforcer after each of three consecutive responses, and a pretraining control group received none. She found that the three-reinforcer group made about seven times more responses than the zero-reinforcer control group during a subsequent period of extinction (actually, a continuation of nonreinforcement for the control group). This comparison did not require a stable preextinction baseline, which in any case was precluded by the brevity of training. Analogously, the effects of prompting and reinforcing compliance with three high-*p* requests on low-*p* compliance can be compared with low-*p* compliance in the absence of the high-*p* series without establishing a stable high-*p* baseline.

The nature of the disrupter. The majority of momentum research has employed disrupters such as prefeeding or free food during periods between components that leave the baseline contingencies unchanged. The high-*p* procedure differs in that its disrupter—a low-*p* request—is simply a more demanding instance of compliance that has already been made probable by the high-*p* sequence. In this sense, it may be more like Harper and McLean's (1992) schedule change, which they characterized as an internal disrupter and, as noted previously, had no differential effects on component performances maintained by different reinforcer magnitudes. However, as described above, Elsmore (1971) employed a demanding ratio as an internal disrupter and obtained results that were entirely in accord with expectations based on momentum research with external disrupters. In summary, the procedures and measures of momentum research can be interpreted as relevant to the effects of the high-*p* procedure on low-*p* compliance.

Some Conceptual Issues

When low-*p* compliance occurs reliably after the high-*p* sequence, is this the result of the velocity of compliance, the mass of compliance, or both (momentum)? This may seem like a scholastic question concerning angels on pinheads, but it is important because of what we know (and don't know) about the separate determiners of the velocity-like and mass-like aspects of behavior.

First, if the high-*p* sequence increases the mass of compliance, it presumably does so through the correlation of reinforcers with the stimulus situation. But as described previously, reinforcement for one class of behavior increases the mass of all behavior that is maintained by the same reinforcer within the situation, including competing responses (as in Component A of Experiment 2 by Nevin et al., 1990). Thus, paradoxically, reinforcing high-*p* compliance may also increase the mass of *non*compliance—whatever the client normally does in response to a low-*p* request in the same situation. At one level, this is not a problem: Because the high-*p* sequence is structured to guarantee that noncompliance does not occur, its local velocity within the high-*p* situation is zero, and its momentum is therefore zero regardless of its mass. However, if noncompliance does occur in the therapy situation, there is a problem of interpretation. Let's assume that compliance is positively reinforced, whereas noncompliance is likely to be negatively reinforced (e.g., by escape from task demands). The question, then, is whether positive reinforcement of one class of behavior also increases the mass of an incompatible class that is maintained by negative reinforcement. No research, to my knowledge, has addressed this question. If future research suggests that both positively and negatively reinforced response classes gain similarly in mass when additional reinforcers are given for the former, a momentum account would have to argue that compliance wins out over noncompliance when a low-*p* request is presented after a high-*p* sequence because the high-*p* sequence selectively increases the velocity of compliance. Future applications of the high-*p* sequence would therefore concentrate on response–reinforcer contingencies that maximize the velocity of compliance. However, if it turns out that positive reinforcers have a selective effect on the mass of positively reinforced behavior, low-*p* compliance would be construed as evidence of the mass of compliance as well as its velocity, and future applications would emphasize situation–reinforcer relations.

Second, the high-*p* series may not be necessary for increasing low-*p* compliance. Although Mace et al. (1988, Experiments 2 and 4) conducted attention controls that included the presentation of pleasant comments with no evidence of enhanced low-*p* compliance, Carr et al. (1976) improved compliance by telling amusing stories in the therapy setting, and Kennedy, Itkonen, and Lindquist (1995) obtained comparable levels of low-*p* compliance by presenting the high-*p* series and by making pleasant comments in separate conditions. These findings appear to be problematic for a momentum account because there is no obvious source of velocity in the absence of the high-*p* sequence. However, they may be understood in relation to the foregoing argument. If amusing stories and pleasant comments are construed as response-independent positive reinforcers, they should increase the mass of compliance in much the same way as the high-*p* sequence reinforcers do. In both studies, compliance had a history of reinforcement in the therapy setting before amusing stories or pleasant comments were introduced. Therefore, the mass of compliance with low-*p* requests might be enhanced by response-independent positive reinforcers, leading to the observed result. (Note that this interpretation works only if such reinforcers did not equally increase the mass of noncompliance, as argued above.) An optimal method for enhancing low-*p* compliance might present explicit response-contingent positive reinforcers in the high-*p* series to establish the velocity and mass of compliance, and also provide response-independent reinforcers in the treatment situation to enhance its mass.

Third, Mace et al. (1988, Experiment 3) did not observe an enhancement in low-*p* compliance when the interval between the high-*p* series and the low-*p* request was increased from 5 s to 20 s. How might a momentum account interpret this transience of low-*p* compliance? One approach is to conceptualize the delay between the high-*p* series and the low-*p* request as an independent disrupter, in addition to the disruptive challenge posed by the low-*p* request itself. Perhaps the delay after the high-*p* series allows other competing behavior to intervene and disrupt compliance; but whatever the interpretation of the delay effect, it should be reduced by any procedure that increases the mass of compliance. For example, response-independent positive reinforcers could be provided in addition to the high-*p* series reinforcers. If the mass-like aspect of compliance is enhanced by such reinforcers, low-*p* compliance should be more resistant to disruption and persist over longer delays. To make more direct contact with the multiple-schedule paradigm, this sort of analysis might profitably be conducted in two physically different settings with two different therapists, one providing response-independent reinforcers in conjunction with the high-*p* series and the other using the high-*p* series alone. Resistance of low-*p* compliance to delay after the high-*p* series could then be compared between settings.

CONCLUSION

In summary, the effectiveness of the high-*p* procedure and its variants can be understood and, perhaps, advanced within the framework of the momentum metaphor from which it developed. However, translating the terms of the metaphor into the high-*p* procedure, or indeed any other application, encounters some uncertainties and entails a fair amount of speculation; thus, alternative accounts are surely possible. Basic research can address these uncertainties, but the direct application of laboratory findings to clinical work with people whose histories and environments are complex and uncontrolled will always involve a certain amount of faith. On the basis of research on resistance to change, I have considerable faith in the power of stimulus–reinforcer relations to influence the persistence of discriminated operant behavior in a wide variety of settings.

My faith is based to some extent on the appeal of the metaphor of behavioral momentum, which continues to guide much of my research. Metaphors can be dangerous if they are extrapolated beyond the domain in which their terms have unambigious referents, but they can also be helpful in communicating scientific ideas. Most important, they may foster innovation because they can interact unpredictably with the repertoires of scientists, as exemplified by the development of the high-*p* procedure.

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APPENDIX

The momentum metaphor links behavioral mass to resistance to change by invoking Newton's second law, which states that the change in velocity of a moving body is inversely related to its mass when a given external force is imposed. More formally,

$$\Delta v = f/m, \tag{1}$$

where Δv is the change in velocity (i.e., acceleration) over the period of force application, f is the imposed force, and m is the inertial mass of the body. For behavioral applications, Nevin, Mandell, and Atak (1983) proposed that Δv be expressed as the logarithm (base 10) of response rate during disruption (B_X) relative to baseline response rate (B_O):

$$\log(B_X/B_O) = f/m, \tag{2}$$

where f is the value of the disrupter and m is behavioral mass. When a given disrupter (f) is applied equally to Components 1 and 2 of a multiple schedule, Equation 2 is written separately for each and the resulting expressions are divided, giving

$$\log(B_{X1}/B_{O1})/\log(B_{X2}/B_{O2}) = m_2/m_1. \tag{3}$$

That is, the ratio of behavioral masses is inversely proportional to the ratio of the logarithms of responding under disruption relative to baseline in the two components. This computation gives a point estimate of the mass ratio, which may be unreliable. If the disrupter value is varied systematically over a series of tests or is defined by a series of consecutive sessions with a given disrupter (e.g., extinction), the ratio of behavioral masses may be estimated more reliably by calculating the slopes of functions that relate response rates under disruption to the value of the disrupter, and quantifying the mass ratio by the inverse slope ratio.

Nevin (1992b) used the inverse-slope analysis to summarize results from a wide variety of procedures employing two-component multiple schedules, multiple chain schedules, and serial schedules that differed in reinforcer rate, magnitude, and contingency between the target response and the reinforcer, with disrupters including free reinforcers between components, signaled concurrent reinforcement, prefeeding, and extinction. He found that the ratio of masses was a power function of a contingency ratio characterizing reinforcer rate or magnitude in one component relative to that in another component, where each was expressed relative to the overall average reinforcer rate or magnitude in the experimental session. In effect, the contingency ratio quantifies the stimulus–reinforcer relation, which has been shown above to be a powerful determiner of resistance to change. Its value can be altered experimentally by changing the reinforcer rate in a target component, the reinforcer rate in an alternated component, or the length of time-out periods between components (which affects the overall average reinforcer rate for a session). Nevin (1992a) showed that these different ways of changing the contingency ratio had similar effects on mass ratios.

The foregoing material addresses the quantification and determiners of behavioral mass. We turn now to velocity, measured as baseline response rate in a multiple-schedule component. Baseline response rate in single schedules is described by Herrnstein's (1970) well-known hyperbolic equation:

$$B = kR/(R + R_E), \tag{4}$$

where B represents response rate, R represents reinforcer rate, R_E represents the rate of extraneous reinforcers, and k represents the asymptotic response rate as reinforcer rate increases indefinitely. Herrnstein (1970) modified the equation to account for interactions in multiple schedules:

$$B_N = kR_N/(R_N + mR_A + R_E), \tag{5}$$

where B_N represents response rate in the target Component N, R_N represents reinforcer rate in that component, and R_A represents reinforcer rate in the alternated component; m, which ranges from 1.0 to 0, represents the degree of interaction between components; and k and R_E remain defined as above. Equation 5 provides an adequate account of response rate in many experiments, but it makes some incorrect predictions and has logical shortcomings. Williams and Wixted (1986) proposed an equation that resolves these difficulties:

$$B_N = sR_N/(R_N + pR_{N-1} + fR_{N+1})/(1 + p + f) + C, \tag{6}$$

where B_N is response rate and R_N is reinforcer rate in the target Component N, R_{N-1} is the reinforcer rate in the preceding component, and R_{N+1} is the reinforcer rate in the following component; p and f reflect the degree of interaction with the preceding and following components, respectively; C represents the inhibitory effects of all reinforcers in the situation; and s is a scaling constant. Equation 6 describes steady-state response rate in a variety of multiple-schedule procedures quite well. If f is greater than p, the equation also accounts for the fact that response rate is lower in the presence of a component with a given reinforcer rate if it precedes a component with a richer schedule than if it precedes a component with a leaner schedule.

Equations 4, 5, and 6 all predict that response rate maintained by a rich schedule will be more resistant to change than that maintained by a lean schedule. This is because a given increase in R_E or C, characterizing the disruptive effect of an external variable (force in the momentum metaphor), will have a relatively smaller impact on B_N if R_N is large than if it is small. This aspect of the equations for asymptotic response rate suggests that a single formulation, such as Equation 6, may be able to describe resistance data as well as response rate, obviating the need for a separate formulation of the relation between behavioral mass and the stimulus–reinforcer contingency. However, these equations cannot handle some aspects of the Nevin et al. (1990) results (see their article for discussion), and they predict the opposite of some data on resistance to change. For example, Nevin (1992a) disconfirmed the predictions of Equations 4, 5, and 6 as extrapolated to resistance to change in a standard two-component multiple schedule when the reinforcer rate in the alternated component varied between conditions. In addition, Equation 6 predicts that both response rate and resistance to change will be greater in a target component with a given reinforcer rate that is preceded or followed by a leaner component schedule than in an identical target component that is preceded or followed by a richer component schedule. However, Nevin (1984) and Nevin, Smith, and Roberts (1987) found that resistance in a target component was greater when it was followed by a richer component, and Tota-Faucette (1991) found that resistance was similarly enhanced regardless of whether the richer schedule preceded or followed the target component.

The results of Nevin (1984), Nevin et al. (1987), and Tota-Faucette (1991) are consistent with the conclusion that behavioral mass depends directly on the stimulus–reinforcer contingency ratio, because their constant target components were embedded within a serial compound defined by a repeating stimulus sequence that was correlated with a distinctive situational cue such as the location of a lighted key. Nevin (1992b; see also McLean, Campbell-Tie, & Nevin, 1996) argued that, for serial schedules, the contingency ratio is the joint product of the reinforcer rate in the target component, relative to the overall session average, and the reinforcer rate in the serial compound within which the target component is embedded, again relative to the overall session average. Nevin (1992b) showed that when the resistance data of serial schedules were analyzed in this way, target-component mass ratios were related to contingency ratios by the same power function as for conventional two-component multiple schedules. Collectively, these analyses suggest that resistance to change in a target component is directly related to the rate of reinforcement obtained in a distinctive stimulus situation, regardless of whether those reinforcers are obtained during, before, or after the target component, and regardless of whether they are allocated to the target response, contingent on an alternative response, or noncontingent.

The conclusion is that steady-state response rate is determined by the rate of reinforcement for a target response, relative to all reinforcers in the experimental situation, as described by Equations 4, 5, 6, or related forms, whereas resistance to change is determined by the rate of reinforcement that is correlated with a target component, irrespective of its source and independent of response rate in that component, as described by a power function relating resistance to a contingency ratio that characterizes the stimulus–reinforcer relation. The independence and separate determination of response rate and resistance to change parallel the independence and separate determination of velocity and mass in classical mechanics, which gave rise to the metaphor of behavioral momentum.