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On the Predictive Validity of Behavioral Momentum Theory for Mitigating Resurgence of Problem Behavior

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Abstract

We summarize the results of four recent translational studies from our lab that used the predictions of behavioral momentum theory to inform the development of more durable treatments for destructive behavior. Treatments informed by behavioral momentum theory generally showed better suppression of target responding during an extinction challenge than did a comparison treatment. We re-analyze data from each of the four studies to show that this general finding is apparent both at the aggregate (i.e., proportion of baseline response rates averaged across participants) and within participant (i.e., percentage reduction in proportion of baseline response rates, difference in raw response rates during the extinction challenge). Interestingly, participants who experienced multiple cycles of the extinction challenge generally showed less differentiation in target responding between the theory informed by behavioral momentum treatment and the comparison treatment. Overall results suggest that applications of behavioral momentum theory can substantially improve the durability of common treatments for destructive behavior.

Keywords

behavioral momentum theory; destructive behavior; functional communication training; noncontingent reinforcement; resurgence

Extensions of behavioral momentum theory (BMT; Nevin, Mandel, & Atak, 1983) to account for the resurgence of operant behavior suggest that resurgence is the result of removing the disruptive impact of alternative reinforcement on target responding (Shahan & Sweeney, 2011; Nevin & Shahan, 2011). According to BMT, alternative reinforcement both disrupts target responding while simultaneously strengthening the target response through Pavlovian processes (Nevin, 1984). When alternative reinforcement is later suspended, a source of disruption is removed, and the target response often resurges, now unencumbered by the disruptive impact of alternative reinforcement.

One important contribution of BMT is the ability to quantitatively describe and predict the resurgence of destructive behavior (e.g., self-injury, aggression, property destruction) following common behavioral treatments, such as differential reinforcement of alternative

behavior (DRA) and noncontingent reinforcement (NCR). For example, functional communication training (FCT; Carr & Durand, 1985) is a DRA procedure wherein the alternative response is a mand for the reinforcer maintaining destructive behavior. Functional communication training may or may not arrange extinction for the destructive response. For example, when destructive behavior is reinforced by adult attention, FCT entails teaching the individual to request attention in a socially appropriate manner (e.g., by saying “Play, please” or by touching or exchanging a picture card inscribed with the same phrase), while destructive behavior may or may not continue to produce attention. Although FCT is commonly used to treat destructive behavior (Petscher, Rey, & Bailey, 2009; Tiger, Hanley, & Bruzek, 2008) and is often effective in doing so (Greer, Fisher, Saini, Owen, & Jones, 2016; Hagopian, Fisher, Sullivan, Acquisto, & LeBlanc, 1998; Kurtz, Boelter, Jarmolowicz, Chin, & Hagopian, 2011; Petscher, Rey, & Bailey, 2009; Rooker, Jessel, Kurtz, & Hagopian, 2013), research has shown that resurgence of destructive behavior readily occurs when FCT is disrupted (e.g., by momentarily placing the alternative response on extinction; Harding, Wacker, Berg, Lee, & Dolezal, 2009; Nevin et al., 2016; Volkert, Lerman, Call, & Trosclair-Lasserre, 2009; Wacker et al., 2011).

When considering resurgence following DRA or NCR, the following equation of BMT is appropriate (Nevin & Shahan, 2011; Shahan & Sweeney, 2011):

$$\frac{B_t}{B_o} = 10^{\left(\frac{-t(c + dr + pR_a)}{(r + R_a)^b} \right)}. \quad (1)$$

Equation 1 asserts that resurgence, expressed as a proportion of baseline response rate, is the exponentiated quotient of the combined influence of variables that disrupt target responding during treatment (i.e., those located in the numerator of Equation 1) divided by the combined influence of variables that strengthen target responding (i.e., those located in the denominator of Equation 1). As you can see, the exponent is negative, indicating that the larger the numerator (i.e., the greater the disruption), the lower the proportion of target responding. Variables that determine the disruption of target responding during treatment include the amount of time spent in extinction (t), the baseline rate of reinforcement for the target response (r), the rate of reinforcement for the alternative response (R_a), as well as a parameter that scales the disruptive impact of R_a on target responding (p) in treatment and two parameters that account for terminating reinforcement for the target response (c and d ; Nevin, McLean, & Grace, 2001). The negative exponent also implies that the smaller the denominator (i.e., less strengthening of the target response), the lower the proportion of target responding. Variables that determine the strength of target responding include the rates of reinforcement for the target response (r) and for the alternative response (R_a), as well as a parameter that accounts for sensitivity to reinforcement (b). When treatment is discontinued (e.g., at the start of an extinction challenge), the disruptive impact of delivering alternative reinforcement on target responding is removed. Thus, pR_a in the numerator goes to zero, but the response-strengthening effects of reinforcement (delivered for both the target and for the alternative response) are maintained in the denominator (Nevin & Shahan, 2011).

Therefore, resurgence, according to BMT, is the result of removing the disruptive impact of alternative reinforcement, given a unique history of reinforcement.

Importantly, Equation 1 suggests a number of manipulations to DRA and NCR treatments for destructive behavior that may reduce the levels of resurgence that occur when alternative reinforcement is suspended. For example, any modification to treatments for destructive behavior that results in less strengthening of target responding should help mitigate resurgence when alternative reinforcement is later suspended. Specifically, BMT suggests that lower rates of reinforcement for destructive (r) and alternative (R_a) behavior should result in less resurgence of destructive behavior than higher rates of reinforcement. Alternatively, resurgence may be reduced by increasing the amount of time that extinction is arranged for destructive behavior (t) or by maintaining some amount of alternative reinforcement in the treatment context.¹ In light of these basic insights, the potential for BMT to inform treatments for destructive behavior is highlighted by four recent studies from our lab (i.e., Fisher, Greer, Fuhrman, Saini, & Simmons, *in press*; Fuhrman, Fisher, & Greer, 2016; Lichtblau, Greer, & Fisher, *in press*; Saini, Fisher, & Pisman, 2017). The purpose of this paper is to summarize and re-analyze data from the four studies described below to investigate the predictive validity of BMT for mitigating resurgence of destructive behavior following alternative reinforcement.

Method

Fisher et al. (*in press*) compared levels of resurgence of destructive behavior following two approaches to assessment and treatment, implementing each approach in a unique stimulus context using a multiple schedule. In baseline, the researchers arranged a lean schedule of reinforcement for destructive behavior in one stimulus context (i.e., the lean-long condition, BMT-informed condition) and a dense schedule of reinforcement for destructive behavior in another stimulus context (i.e., the dense-short, comparison condition). Following baseline, they introduced a phase of FCT in which they arranged the same schedule of reinforcement used in baseline for the alternative response in each respective context (i.e., a leaner schedule of alternative reinforcement in the lean-long condition relative to that in the dense-short condition). Destructive behavior in both contexts produced no programmed consequences during treatment. Additionally, participants experienced three times the number of FCT sessions in the lean-long condition than in the dense-short condition. Finally, in the extinction challenge, neither destructive behavior nor the alternative response produced reinforcement in either context, and therapists delivered reinforcers according to a variable time (VT) 200-s schedule. All four participants engaged in proportionately lower levels of destructive behavior in the lean-long condition relative to those in the dense-short condition during the extinction challenge.

Fuhrman et al. (2016) compared levels of resurgence following two approaches to FCT. The researchers predicted that thinning the schedule of alternative reinforcement using discriminative stimuli in the context of a multiple schedule would better mitigate resurgence

¹A hands-on tutorial recently published by Greer, Fisher, Romani, and Saini (2016) demonstrates these and other predictions of BMT in a series of learning activities that build upon one another in complexity. We encourage interested readers to consult this potential resource.

when compared to a traditional schedule in which discriminative stimuli were not present and the schedule of alternative reinforcement was not thinned. Two participants experienced a reversal design in which each condition included a sequence of three phases (i.e., baseline, FCT, extinction challenge). Destructive behavior produced reinforcement on a variable interval (VI) 40-s schedule in both baseline conditions. During both variations of FCT, the researchers arranged extinction for destructive behavior. With the multiple schedule, therapists signaled the availability (S^D) and unavailability (S^-) of reinforcement for the alternative response and thinned the schedule of reinforcement for the alternative response by increasing the amount of time spent in the presence of the S^- . With the traditional schedule, the alternative response produced reinforcement on a VI 20-s schedule. Finally, in the extinction challenge, neither destructive behavior nor the alternative response produced reinforcement, and therapists delivered reinforcers according to a VT 200-s schedule. Therefore, the two FCT treatments differed in terms of the presence (multiple schedule) or absence (traditional schedule) of discriminative stimuli and the fact that the multiple schedule included schedule thinning and the traditional schedule did not. In addition, the S^- remained present during the extinction challenge in the multiple-schedule condition to signal the continued unavailability of reinforcement for the alternative response. Fuhrman et al. observed lower levels of resurgence during the extinction challenge of the multiple-schedule condition for both participants.

Lichtblau et al. (*in press*) used a reversal design similar to that used by Fuhrman et al. (2016) to compare levels of resurgence following FCT implemented with and without extinction. Destructive behavior produced reinforcement on a VI 10-s schedule in baseline. In FCT without extinction, destructive behavior continued to produce reinforcement on the same VI 10-s schedule as in baseline, and the alternative response produced reinforcement on a VI 5-s schedule. In FCT with extinction, destructive behavior produced no programmed consequences, and the alternative response produced reinforcement on a VI 5-s schedule. Additionally, Lichtblau et al. yoked the reinforcement rates across FCT treatments by delivering NCR in FCT without extinction. That is, the two treatments differed only in the presence or absence of programmed consequences for destructive behavior during FCT. In the extinction challenge, neither destructive behavior nor the alternative response produced reinforcement, and therapists delivered reinforcers according to a VT 200-s schedule. Both FCT treatments suppressed baseline rates of destructive behavior; however, Lichtblau et al. observed lower levels of resurgence following FCT with extinction in three of the four treatment comparisons.

Finally, Saini et al. (2017) evaluated resurgence following NCR implemented with and without extinction using a human-operant preparation. Following baseline wherein pressing a button (an analog of destructive behavior) produced reinforcement on a VI 30-s schedule in both conditions, Saini et al. introduced a VT 30-s schedule of reinforcement. In one treatment analog, the baseline schedule of reinforcement remained in effect (i.e., VI 30 s + VT 30 s), whereas in the other treatment analog, the baseline schedule of reinforcement terminated (VT 30 s). Saini et al. then terminated reinforcement in both conditions. For all three participants, resurgence was greater in the treatment analog associated with continued reinforcement of the target response and with a relatively higher rate of reinforcement (i.e., VI + VT).

We conducted the primary analyses reported below on rates of destructive behavior during the extinction challenge of each of the studies described above. Within each of these studies, the number of sessions included in the extinction challenge varied across participants. Thus, to facilitate comparisons of resurgence obtained following the BMT-informed and comparison treatments, we first identified the fewest number of sessions any participant experienced within an extinction challenge separately for each study. We then truncated the data for all remaining participants after that session so that we analyzed the same number of sessions for each participant.

To explore the ability of BMT to quantitatively characterize resurgence in each of these studies, we fitted Equation 1 to the mean proportion-of-baseline response rates in the extinction challenge. We calculated the proportion of baseline as follows. For each participant, we first averaged the response rates from the last five sessions of each baseline condition. Then, we divided the response rates during each session of the extinction challenge for a given treatment by the mean rate of responding from its respective baseline. If participants experienced replications (as in the cases of Fuhrman et al., 2016; Lichtblau et al., *in press*; Saini et al., 2017), we averaged the proportion-of-baseline response rates from each replication.

For model fits, we entered p , c , d , and b from Equation 1 as free variables constrained only to minimize the sum of squared residuals across participants and treatments between obtained and predicted proportions of baseline target responding using Microsoft Excel Solver. We calculated the reinforcer-rate parameters r and R_d separately for each treatment by setting those parameters equal to the mean (across participants and sessions) rate of reinforcement obtained during the final five sessions of each baseline condition and the mean rate of reinforcement during treatment, respectively. For the studies that included the delivery of VT reinforcers during the extinction challenge (as in the cases of Fisher et al., *in press*; Fuhrman et al., 2016; Lichtblau et al., *in press*), we retained R_d in the numerator during the extinction challenge and set its value equal to the mean rate of VT reinforcement obtained during the challenge. Finally, we determined time in extinction (t) for the first session of the extinction challenge for each treatment in the Fisher et al. and Fuhrman et al. studies by averaging across participants the number of sessions with extinction in place before the challenge and then rounding to the nearest whole number. For the Lichtblau et al. and Saini et al. studies (in which we manipulated the presence or absence of extinction for target responding), we set $t = 1$ for the first session of the extinction challenge for the treatment that did not arrange extinction for target responding. Conversely, for the treatment that arranged extinction for target responding, we averaged the number of treatment sessions across participants and then set t to equal this average for the first session of the extinction challenge.

As reviewed above, Fuhrman et al. (2016) presented a discriminative stimulus associated with non-reinforcement during the extinction challenge in the BMT-informed treatment. Nevin et al. (2017) suggested that influences of contextual stimuli on response persistence may be best characterized by adding an additional disruptor term to the numerator of Equation 1. Thus, for fits of Equation 1 to data from this experiment, we included an

additional free parameter (d_c) for the BMT-informed treatment to capture potential suppressive effects on resurgence produced by presence of the S .

Results and Discussion

Figure 1 displays average proportion of baseline target responding during the final two sessions of treatment, as well as during the extinction challenge that followed the BMT-informed and comparison treatments in the studies by Fisher et al. (*in press*), Fuhrman et al. (2016), Lichtblau et al. (*in press*), and Saini et al. (2017). Target responding in the final two treatment sessions were similarly low across the two treatments evaluated by Fisher et al., Fuhrman et al., and Saini et al. Considerably more target responding occurred in the study by Lichtblau et al. in the final sessions of the FCT treatment implemented without extinction than in the FCT treatment implemented with extinction. Target responding increased for each study in at least one of the two conditions when participants transitioned from treatment to the extinction challenge, demonstrating resurgence. For all studies, transitioning from treatment to the extinction challenge produced larger increases in target responding for the comparison condition than for the BMT-informed condition. Model fits of Equation 1 to the data from the extinction challenge also appear in Figure 1. Visual inspection suggests that average proportion of baseline target responding was lower across all four studies in the BMT-informed treatment than in the comparison treatment during the extinction challenge.

Equation 1 provided a reasonable account of the average proportion of baseline target responding across BMT-informed and comparison treatments in the Fisher et al. (*in press*) and Fuhrman et al. (2016) studies (see Table 1 for parameter estimates of Equation 1 for the data displayed in Figure 1). In neither study did the model systematically underpredict or overpredict resurgence in either treatment. That is, distribution of residuals fell roughly evenly around 0. It is notable that estimated parameter values in these two studies approximated those often reported in studies of resurgence using nonhuman animals (cf. Shahan & Sweeney, 2011).

Relative to the model fits described above, Equation 1 did a relatively poor job describing data from the Lichtblau et al. (*in press*) and Saini (2017) studies. Average proportions of baseline target responding in the study by Lichtblau et al. varied widely, resulting in large residuals between predicted and obtained resurgence. The model underpredicted resurgence in the comparison treatment (i.e., positive residuals for 8 of 10 data points) and slightly overpredicted resurgence in the BMT-informed treatment (i.e., negative residuals for 6 of 10 data points). The model's inaccuracies may be due to the comparison treatment often yielding average proportions in excess of 1.0. Equation 1 cannot accommodate proportional values in excess of 1.0 due to its negative exponentiation. Despite this limitation, none of the average proportions exceeded 1.0 in the BMT-informed treatment of the Lichtblau et al. study.

Equation 1 suggests that the BMT-informed treatment of the study by Saini et al. (2017) should have produced near-complete suppression of target responding during the extinction challenge, which occurred for only half of the comparisons (see Figures 1, 2, and 3 in Saini et al., 2017). These between-participant differences led to poor model fits of Equation 1 to

the BMT-informed treatment of the Saini et al. study. That is, the model systematically underpredicted resurgence in the BMT-informed treatment (i.e., positive residuals for all seven data points).

The BMT-informed treatment in the studies by Saini et al. (2017) and Lichtblau et al. (*in press*) arranged extinction for target responding, whereas the target response continued to produce reinforcement in the comparison treatment. Equation 1 predicts time in extinction (t) to have a relatively large impact on the level of resurgence, with more time in extinction producing less resurgence. Extending this assertion to the present results, Lichtblau et al. arranged a shorter treatment duration (range 5 to 7 sessions per cycle) than did Saini et al. (range 18 to 25 sessions per cycle), and the additional time in extinction during the BMT-informed treatment in the Saini et al. study relative to that arranged in the Lichtblau et al. study contributed greatly to the differences in the model fits of Equation 1 to the BMT-informed treatment across these two studies.

It is also important to note that modeling with Equation 1 to data from the Lichtblau et al. (*in press*) and Saini et al. (2017) studies produced atypical parameters (see Table 1). Estimated values of c , b , and, in the case of the Lichtblau et al. study, p , equaled 0. Thus, the model suggests no disruptive impact on resurgence of suspending the contingency between target responding and reinforcers or of delivering alternative reinforcers. More problematically from a theoretical standpoint, the Pavlovian relation between reinforcers and stimuli in the clinical context ($r + R_d$) did not contribute to response persistence because any value raised to the power of 0 = 1. Clearly, there are sources of variation in resurgence data from these studies for which Equation 1 does not account. Nevertheless, BMT accurately predicted *ordinal* differences in resurgence between treatments, thus demonstrating some degree of predictive utility when applied to these data.

Figure 2 displays the percentage reduction in target behavior during the extinction challenge resulting from the modifications made to the BMT-informed treatment (relative to the absence of those modifications in the comparison treatment) when analyzing the proportion of baseline target responding produced by each of the two treatments. That is, Figure 2 shows the relative amount of target behavior *not observed* in the extinction challenge as a result of the modifications made to the BMT-informed treatment. Across participants, these reductions averaged 69.7% (range 56.2% to 83.1%) in Fisher et al. (*in press*), 74.7% (range 35.6% to 90.8%) in Fuhrman et al. (2016), 38.3% (range -1.2% to 73.1%) in Lichtblau et al. (*in press*), and 57.4% (range 31.2% to 97.0%) in Saini et al. (2017).

Two points are worth discussing in relation to these data. First, it is important to reiterate that destructive behavior displayed by children with autism and related conditions served as the target response in three of the four studies (Fisher et al., *in press*; Fuhrman et al., 2016; Lichtblau et al., *in press*). Across all participants of the three studies that targeted destructive behavior, we observed a 60.9% (range, -1.2% to 90.8%) reduction in the proportion of baseline rates of destructive behavior in the BMT-informed treatment relative to the proportions measured in the comparison treatment. Second, five participants (Ben and Alex in Fuhrman et al., Charlie and Dan in Lichtblau et al., and Gen in Saini et al.) experienced multiple cycles of the extinction challenge using the reversal design described above. Four

of these five participants (Alex, Charlie, Dan, and Gen), showed markedly less reduction in the BMT-informed treatment relative to the comparison treatment during the second cycle of the extinction challenge when compared to reductions observed in the first cycle (see the individual participant data presented in each of those studies). These results are consistent with Equation 1, which predicts that successive exposures to extinction should increase t and result in progressively lower levels of resurgence.

The data displayed in Figure 3 highlight several of these findings at the level of individual participants. Data points here reflect differences between the raw response rates measured in the extinction-challenge sessions of the BMT-informed treatment and those measured in the corresponding sessions of the comparison treatment, plotted across sessions of the extinction challenge. Thus, negative values indicate lower rates of resurgence in the BMT-informed treatment than in the comparison treatment. Additionally, data from participants' first and second cycles of the extinction challenge are plotted separately. The results show generally lower raw response rates during the extinction challenge of the BMT-informed treatment than the corresponding rates in the comparison treatment, and this difference tended to be more pronounced in earlier sessions of the extinction challenge and in the first cycle of the extinction challenge for participants who experienced multiple cycles of the extinction challenge.

As an overall test of the effectiveness of the BMT-informed treatment, we calculated paired sign tests using the binomial distribution on the data in Figure 3 against the null hypothesis that $p_{success} = .5$ (i.e., a 50% chance of one treatment producing greater resurgence than the other treatment). That is, we asked whether we had evidence that responding was lower in the BMT-informed treatment than in the comparison treatment during the extinction challenge. Responding was reliably lower in the BMT-informed treatment in the Fisher et al. (*in press*), Fuhrman et al. (2016), and Saini et al. (*in press*) studies ($p_s \leq .05$) and trended toward significance in the Lichtblau et al. study ($p = .053$).

Conclusions

All four of the studies summarized in the current investigation analyzed resurgence in a three-phase arrangement with (a) reinforcement scheduled for destructive behavior (or an analog of destructive behavior) according to a VI schedule in the first phase (i.e., baseline), (b) reinforcement arranged for an alternative response on either a VI or a VT schedule in the second phase (e.g., DRA) with or without extinction arranged for destructive behavior, and (c) extinction arranged for both destructive behavior and the alternative response in the third phase (i.e., extinction challenge). The studies differed in a variety of ways (e.g., analog versus actual destructive behavior as targets, antecedent versus schedule manipulations, multiple-schedule versus reversal design). Nevertheless, in each study, we observed clinically and statistically significant reductions in resurgence of the target response in the BMT-informed treatment relative to the comparison treatment.

These results are potentially important because they show the utility of BMT for addressing problems of social importance, despite recent basic studies identifying areas in which the predictions of BMT have proven inaccurate (Craig & Shahan, 2016; Nevin et al., 2017;

Sweeney & Shahan, 2013). Our results show that BMT may be clinically relevant and useful even though it may fail to account for some experimental findings under certain circumstances. The differences between our results and the findings of these prior basic investigations highlight an important distinction between basic and applied investigations that researchers interested in translational research should consider. That is, basic researchers often look for situations for which the competing quantitative theories of behavior make different or conflicting predictions about behavioral outcomes (Mazur, 2006). By contrast, applied researchers look for theories that lead to relatively clear, consistent, and clinically significant improvements in behavior of social importance. As such, clinicians may be more interested in those situations in which the predictions of competing quantitative theories of behavior converge (rather than diverge) because those predictions are likely to have more robust beneficial effects in practice.

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Figure 1.

Target responding obtained (data points) and modeled (curves) during the final two sessions of treatment as well as during the extinction challenge of each study expressed as a proportion of baseline response rate averaged across participants. BMT-informed and comparison treatments differed across studies but responding in each appears here as open and closed data points, respectively. See text for a description of each study.

Figure 2.

Percentage reduction in proportion of baseline responding in the BMT-informed treatment relative to the comparison treatment during participants' first (filled bars) and second (striped bars) cycles of the extinction challenge in each study. Positive values indicate relatively greater suppression of target responding in the BMT-informed treatment than in the comparison treatment.

Figure 3.

Differences between target response rates in the BMT-informed treatment and those in the comparison treatment during participants' first (closed data points) and second (open data points) cycles of the extinction challenge in each study. Negative values indicate lower response rates in the BMT-informed treatment than in the comparison treatment.

Table 1

Parameter Estimates Across Studies

Study	Parameter Estimate				
	<i>p</i>	<i>c</i>	<i>d</i>	<i>b</i>	<i>d_c</i>
<i>Fisher et al.</i>	0.07	1.46	0.0008	0.82	-
<i>Fuhrman et al.</i>	0.03	0.02	0.0019	0.42	0.51
<i>Lichtblau et al.</i>	0.00	0.00	0.0002	0.00	-
<i>Saini et al.</i>	-	0.00	0.0010	0.00	-

Note. Saini et al. was the only study that did not deliver alternative reinforcement in the extinction challenge. Thus, *p* is undefined for this study.