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TEMPORAL DYNAMICS OF EXTINCTION-INDUCED BEHAVIOR: A HUMAN-OPERANT ANALYSIS

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We examined the disruptive effects of unsignaled transitions to extinction in two-component mixed schedules on human-operant performance with individuals with intellectual and developmental disabilities. We document the temporal dynamics of operant performance and indices of behavioral flexibility during extinction. Across two studies, transitions to extinction were marked by changes in the microstructure of interresponse times underlying the target response. Decreases in the target response during extinction were attributed to a lengthening of pauses in-between bouts of responding. Our results are consistent with nonhuman work from the basic laboratory demonstrating that extinction-induced behavior occurs in bouts and pauses, and further suggests that bout-initiation rates during extinction are influenced by motivational variables such as reinforcer quality. We discuss implications for applied research and clinical practice, particularly as it relates to the study of behavioral mechanisms underlying persistence in treatment-resistant self-injurious behavior.

Keywords: bout; extinction; human-operant; self-injurious behavior; temporal dynamics

Operant behavior often occurs in bouts and pauses (Shull et al., 2001). Bouts refer to periods of engagement in a target response (e.g., eating) that alternate with pauses associated with periods of disengagement from the target response during which the organism engages in other activities (e.g., foraging). The idea that responding occurs in bouts and pauses is used in the fields of neurotoxicology and behavioral neuroscience to disentangle the contribution of motivational and motoric variables to changes in operant behavior (e.g., Cheung et al., 2012). This is possible because a wealth of research demonstrates that the duration of pauses (i.e., the intervals occurring between bouts) are selectively affected by motivational variables including reinforcement rate, quality, deprivation, and alternative reinforcer availability (e.g., Shull, 2004). In contrast, within-bout response rates are selectively affected by operations affecting the motoric elements or physical dimensions of the response unit, including pharmacologic agents (Hoffman & Newland, 2016) or response force requirements (Brackney et al., 2011).

When a behavior is characterized by bouts and pauses, a microstructural analysis of its interresponse times (IRTs) often reveals a mixture of two exponential distributions (Shull et al., 2001). One distribution corresponds to short IRTs within ongoing response bouts, reflecting motor properties of the operant, and the other corresponds to pauses associated with longer intervals between bouts, reflecting the motivation behind the response. Partitioning the ebb and flow of behavior in this manner (short IRTs→bouts; long IRTs→pauses) facilitates analysis of the mechanisms underlying behavior maintenance and change. This microstructural analysis of behavior provides insight into variables that are otherwise obscured or undetectable with molar accounts of behavior concerned with response rate alone (Shull et al., 2001; Shull, 2004; Shull, 2011).

Whereas some operations primarily alter the duration of pauses between bouts of activity (i.e.,

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long IRTs), others tend to alter the within-bout responses (i.e., short IRTs). For example, Blough (1963), using a camera mounted on a cathode-ray tube oscilloscope to continuously track pigeons' IRT distributions in real time, was among the first to examine the relative sensitivity of short and long IRTs during transition states from reinforcement to extinction. He found evidence of differential sensitivity of short and long IRTs to changes in reinforcement contingencies—when transitioning from a variable interval 4 min schedule to extinction, the short IRTs forming within-bout responses were generally unchanged but the longer IRTs forming the inter-bout intervals were markedly increased. Thus, the source of the decline in response rates in extinction was attributed to changes in IRTs forming the inter-bout intervals, and not necessarily the IRTs composing the within-bout responses.

This example illustrates how a microstructural analysis of behavior can elucidate behavioral mechanisms of extinction performance that cannot be deduced based on overall response rates alone (Brackney et al., 2017; Cheung et al., 2012). In the present investigation, we document the microstructure and temporal dynamics of operant task performance during extinction using several approaches that supplement response rate as an index of behavioral variation and sensitivity to change. Across two studies, individuals with intellectual and developmental disabilities (IDD) completed a human-operant task involving two-component mixed schedules with transitions from continuous reinforcement to extinction. In Study 1, we examined the microstructure of extinction-induced behavior in an operant task with an 11-year-old boy diagnosed with autism spectrum disorder, mild intellectual disability, and attention-deficit/hyperactivity disorder (ADHD). In Study 2, we reanalyzed data from Rooker et al. (2019) involving a similar operant task with six individuals with IDD.

STUDY 1

Participant and Setting

Ben was a 11-year-old boy referred to a hospital-based treatment unit for the assessment and treatment of challenging behavior. Sessions were conducted in the patient's bedroom on the unit away from other patients. Session materials consisted of a desk, two chairs, edible stimuli, and a microswitch in the form of a button.

Procedure

The experimental analysis was nearly identical to the procedure described by Rooker et al. (2019). Prior to the experimental analysis, we conducted paired-stimulus preference assessment to identify a moderately preferred (MP) stimulus (Animal Crackers) for use in the operant task described below. Following the preference assessment, we verified that the MP stimulus functioned as a reinforcer via an ascending series of fixed-ratio (FR) schedules (e.g., Reilly, 2003; data available upon request). During the operant task, Ben was seated at a table across from the experimenter and a microswitch was placed within his reach. Responding for the MP stimulus was evaluated in a single session using a two-component mixed schedule consisting of a 3-min reinforcement component (FR-1) followed by an unsignaled transition to a 7-min extinction component. During the reinforcement component, each target response produced one piece of food, which was presented by the experimenter. When the reinforcer was delivered, the experimenter removed the microswitch the participant accepted the food item by placed it past the plane of the lips. Time to consume food during the reinforcement component was included in all analyses below. During extinction, the target response did not produce any programmed consequences. Laptop computers were used to collect data on switch presses during the experiment proper using BDataPro software (Bullock et al., 2017).

Data Preparation and Analysis

Band Plots

Central to the dynamical description of behavior during transition states is the display of the dependent behavioral variable as a function of time. Band plots display each IRT as a function of time or serial position, as demonstrated by Blough (1963; see Figure 1) and others (e.g., Weiss & Gott, 1972). IRTs were calculated using conventional methods, such that the IRT for the very first target response (i.e., pressing the microswitch) in each session was measured from the start of the session, and IRTs for all subsequent target responses within that session were measured from onset from the prior response (e.g., Shull et al., 2001).

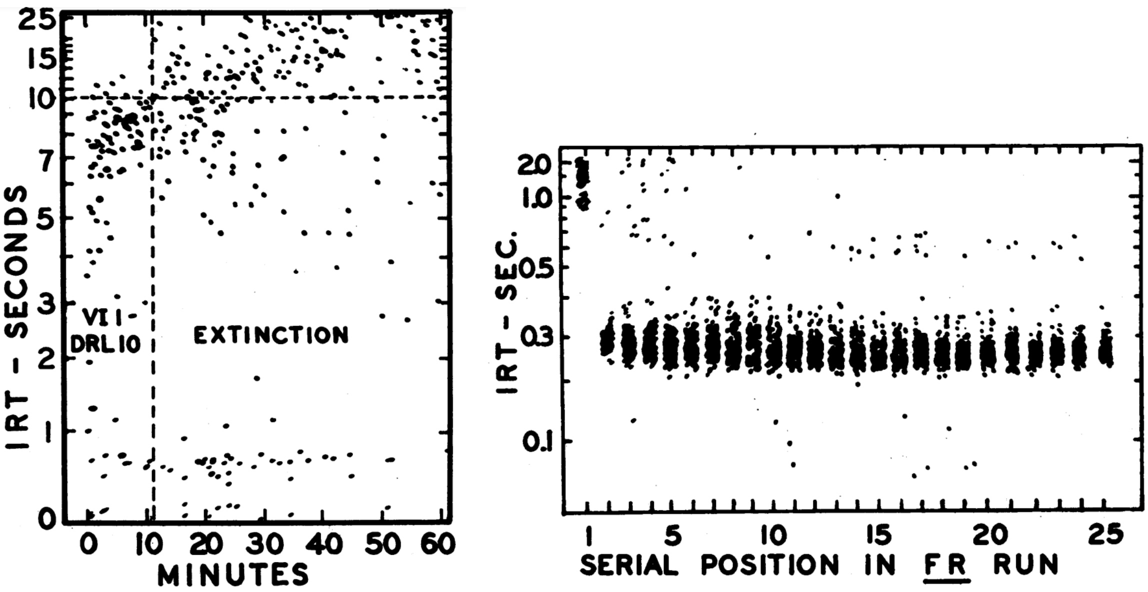

Figure 1. Two Band Plots from Blough (1963). *Note:* Each dot depicts in an individual IRT. The band plot on the left displays changes in IRTs after an unsignaled transition to extinction following a tandem VI-DRL reinforcement component for a single pigeon. The band plot on the right displays IRTs during 100 successive runs in a FR 25 reinforcement schedule. Notice how, once a bout a responding occurs, there is minimal variation in the within-bout interresponse times. This pattern is consistent with a two-mode conceptualization of behavior. Here, pecking is analogous to a constant-speed motor. Once the motor is turned on, it runs at a constant speed (i.e., within-bout response rate); however, the amount of time the motor takes to turn off once started (i.e., bout length)—and the duration of time the motor subsequently stays off (i.e., between-bout pauses) may vary depending on the schedule of reinforcement and other variables (Shull, 2011). Figures reprinted with permission from Blough (1963).

Return Plots

Return plots, also referred to as return maps or joint interval plots, are used to examine the dynamics of mechanical systems (Shaw, 1984) and have been extended to behavioral dynamics as well (Li & Huston, 2002; Palya, 1992; see also Pevey et al., 1992). These are a coarse version of a Poincaré plot because the state of the system is sampled in an irregular period (Marr, 1992). Return plots portray the degree to which each IRT is influenced by the value of the IRT that preceded it (IRTn-1). Thus, this technique involves plotting each IRT as a function of the preceding IRT or other lagged IRTs (Mechner, 1958). As described by Palya (1992), these plots can be seen as a graphical implementation of a contingency table—the position of a dot with respect to the y-axis depicts the IRT of a microswitch press n. The position of that dot with respect to the x axis depicts the IRT of the preceding microswitch press. Thus, a comparison on two vertical slices of data reveals the distribution of IRTs as a function of the preceding IRTs. Return plots can yield insight into (1) the periodic or nonperiodic nature of IRTs, (2) whether there are dependencies between successive IRTs, (3), and whether there is a stable, invariant structure of IRTs that is relatively insensitive to variations in the schedule (Marr, 1992; see Figure 2 for examples).

An interesting variation of the return plot, commonly used with financial time-series data (e.g., Akgiray, 1989), involves calculating the logarithmic return of a signal over time to identify dominant frequencies, periodicities, or cyclical patterns in the data:

$$log\left(\frac{IRT_n}{IRT_{n-1}}\right) \tag{1}$$

—as applied to IRTs, this entails plotting the logarithm of the quotient of each IRT by IRT$_{n-1}$. This is equivalent to subtracting the logarithm of IRTn-1 from the logarithm of the current IRT, which normalizes the time series data and facilitates visual analysis of IRTs spanning multiple orders of magnitude.

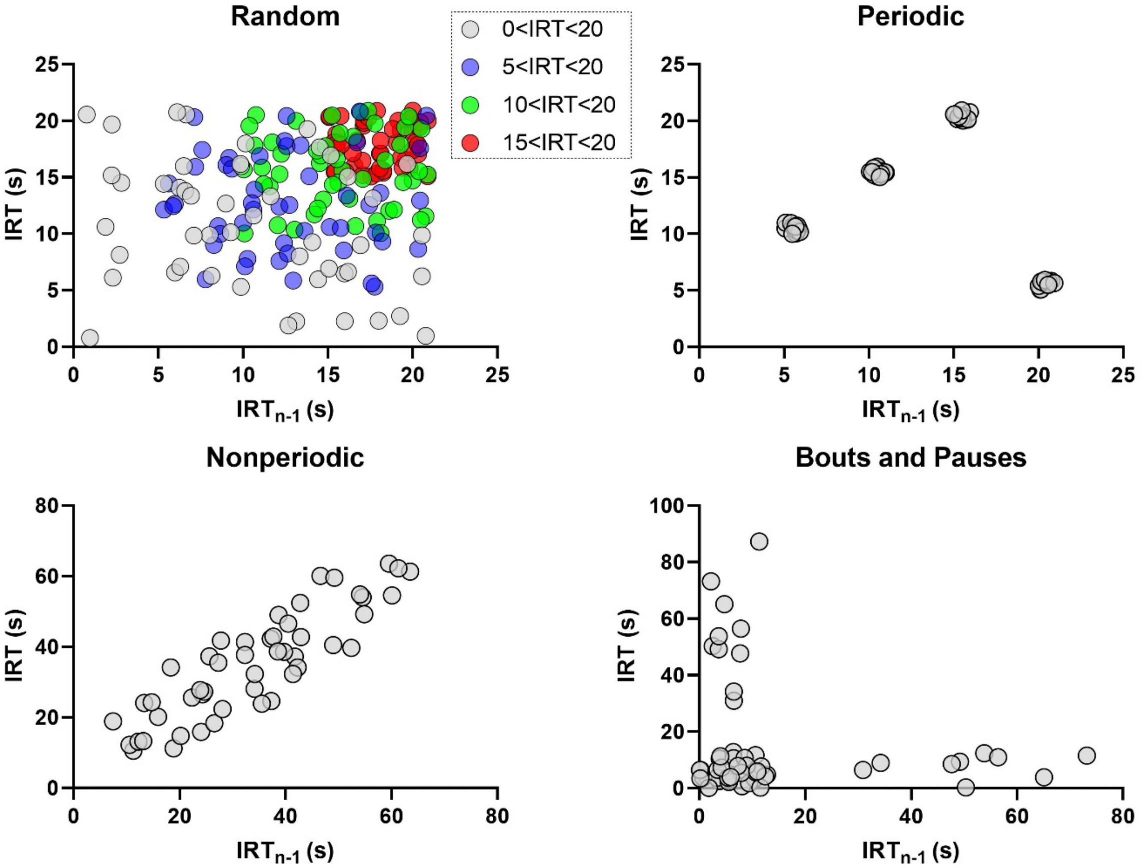

Figure 2. Illustrative Return Plots. *Note:* Above we demonstrate how return plots of IRTs can provide some insight into the temporal structure of behavior. Each data point in these panels corresponds to an IRT. Panel A shows a return plot produced with a range of randomly generated IRT values between 0 s and 20 s, 5 s and 20 s, 10 s and 20 s, or 15 s and 20 s (along with a small amount of added noise). Notice how the IRTs begin to cluster together as the range of IRT values gets smaller and smaller, indicating the presence of stereotypic responding with little temporal variation. Now imagine the IRTs are generated from a process such that they occur in the following repeating sequence: 5 s, 10 s, 15 s, 5 s, 10 s, 15 s...and so on. This pattern would produce an outcome similar to that shown in Panel B, which reveals the periodic aspect of this sequence. On the other hand, imagine that IRTs are generated by a process where an IRT is randomly selected from a range of values between 0 s and 20 s, with 1 s added to the first IRT, 2 s added to the second IRT, 3 s added the third IRT, etc. As shown in Panel C, a return plot of IRTs generated by this process would reveal that the duration of time in-between IRTs increases linearly within-session. Finally, Panel D shows a return plot produced with IRTs generated from a process yielding two distributions of IRTs (one short and one long). Short IRTs are primarily followed by short IRTs (i.e., bouts) except for an occasional long IRT (i.e., inter-bout interval), as indicated by the symmetry around the main diagonal near the origin of the return plot.

Log Survivor Plots

Bouts and pauses are identifiable through analysis of IRT distributions corresponding to short and long IRTs, respectively. This approach is predicated on the idea that there are two functionally distinct frequency distributions of IRTs for a given target response—one for pauses between bouts of responding and one for responses occurring within a bout of responding—that can be assayed using visual and mathematical techniques described below. This bout-analytic method entails plotting the proportion of IRTs among a representative sample of unconstrained responses that are longer in duration than some time (ti) as a function of time (t) on a semi-logarithmic scale. Responding that is not organized into bouts and pauses appears as a single, negatively accelerated line (Shull et al., 2001). In contrast, responding that occurs in bouts and pauses is indicated by a characteristic "broken stick" appearance indicating periods of high-rate responding within bouts (short IRTs) and long pauses in-between bouts (long IRTs). This "broken-stick" appearance indicative of a clear bout structure consists of two distinct limbs: the steeply sloped left limb of the log survivor plot corresponds to within-bout IRTs, and the right limb corresponds to long IRTs associated with between-bout pauses (e.g. Kulubekova & McDowell, 2008). A number of operations involving schedule manipulations, motivational manipulations, pharmacological manipulations, and effort-related manipulations have all shown to selectively affect one of these limbs or the other (e.g. Shull, 2011).

This conceptualization of two-mode responding can further be modeled quantitatively as the sum of two exponential decay processes to provide measurable parameter estimates of motivational factors (i.e., pauses between bouts) and motoric factors (i.e., within-bout response rate) related to the target response:

$$r(t) = (1 - p)e^{-wt} + e^{-bt} \tag{2}$$

in which $r(t)$ is the proportion of IRTs longer than a given amount of time (t), p is the proportion of responses that are bout initiations, w is the estimated within-bout response rate, b is the estimated rate of bout initiations, t represents time since the last response, and e is the base of the natural logarithms.

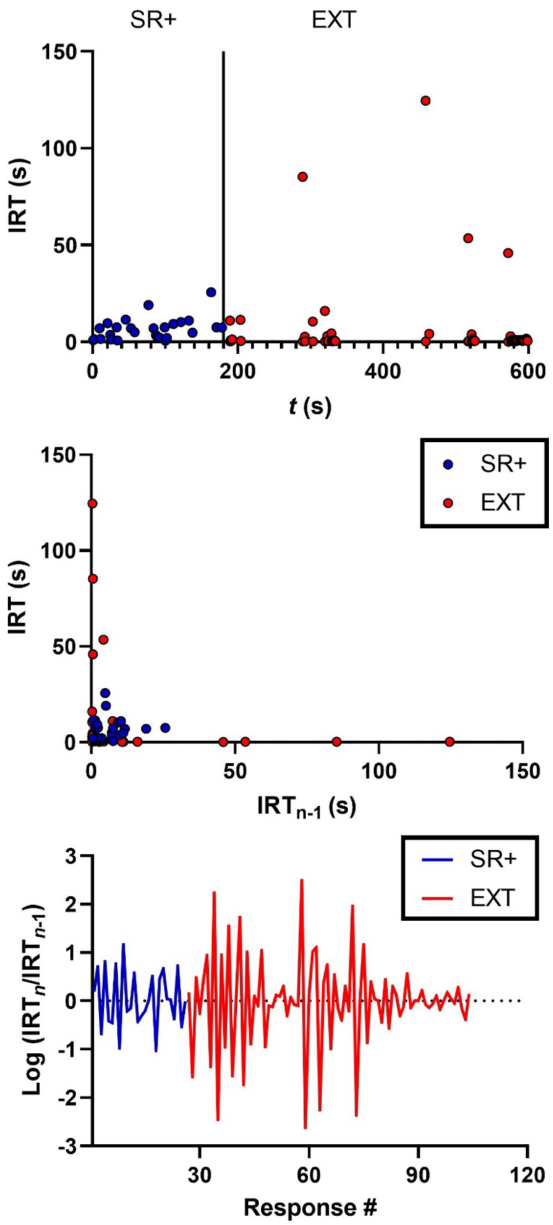

Figure 3. Band Plots and Return Plots. *Note:* SR+ = reinforcement condition; EXT = extinction condition.

RESULTS AND DISCUSSION

Visual analysis of the band plot depicting the IRT for each target response as a function of time in session revealed little variation in the IRTs of the target response during the reinforcement component of the mixed schedule (Figure 3, top panel). This finding is consistent with extant laboratory findings with nonhuman animals that very dense FR schedules tend to engender short IRTs (e.g., Crossman et al., 1987). During the extinction component, there was a lengthening of a subset of the IRTs characteristic of responding becoming organized into bouts and pauses. There was no obvious periodicity in the organization of the IRTs during extinction, indicated by the symmetry around the main diagonal near the origin of the return plot (Figure 3, middle panel). Changes in the long IRTs associated with the transition from reinforcement to extinction spanned several orders of magnitude as the variability of IRTs increased considerably during the transition from reinforcement to extinction, indicating marked changes in the relative length of IRTs from response to response (Figure 3, bottom panel).

These results point to two different distributions of IRTs associated with operant extinction—short IRTs, corresponding to bursts of responding within ongoing bouts of button pressing, and long IRTs corresponding to relatively long pauses in button pressing during the inter-bout intervals. Results of the log survivor plots during the reinforcement component (Figure 4, top panel) and extinction (Figure 4, bottom panel) confirm this this notion. Whereas the log survivor plot for the IRTs obtained during the reinforcement component consists of a single limb, the transition to extinction was associated with the formation of a "broken-stick" plot with a discernable right limb corresponding to relatively long pauses between bouts of responding. The fit of Eq. 2 to the IRTs from the extinction component was excellent (VAC = 98.8%), with the obtained parameter estimates indicating an average within-bout response rate of 1.9 button presses/sec, bout length of 7.6 responses, and pause duration of 51.5 sec between bouts of button pressing.

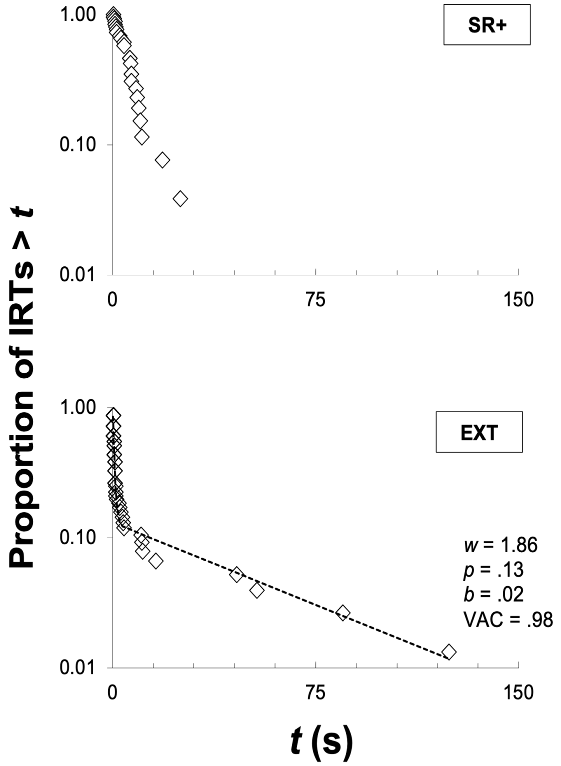

Figure 4. Log Survivor Plots for Reinforcement and Extinction Components. *Note:* SR+ = reinforcement condition; EXT = extinction condition. Data points correspond to IRTs; dashed lines correspond to best-fit lines from Eq. 2; w = within-bout response rate (resp/s); p = proportion of responses that are bout initiations; b = bout-initiation rate (resp/s).

This simple demonstration highlights how the microstructural analysis of extinction-induced behavior has the potential to elucidate some of the behavioral mechanisms underlying persistence and change. These analytic methods may be useful for understanding the variables contributing to extinction deficits in clinical populations and animal models of psychopathology (e.g., Brackney et al., 2011). For example, this approach may provide insight into the phenomenology of self-injurious behavior (SIB) because extinction deficits have been documented in organisms who engage in SIB. For example, following trials with reinforcement, rhesus macaques with a veterinary record of SIB show more persistent lever pressing during extinction trials compared to monkeys with no record of SIB (Lutz et al., 2004). It is possible that a microstructural analysis of operant performance could provide additional insight into some of the behavioral mechanism underlying behavioral persistence during extinction.

Self-Injurious Behavior

Among individuals with IDD, SIB is often maintained by social consequences (e.g., caregiver attention). However, in approximately 25% of cases SIB occurs independent of social contingencies (e.g., Iwata et al., 1994). This class of behavior is referred to as automatically maintained SIB. Among this class, several distinct patterns of SIB are well-documented. One pattern is characterized by elevated levels of SIB in environments with minimal background reinforcement (e.g., the no-interaction condition of a functional analysis), and diminished levels of SIB in conditions with higher levels of background reinforcement (Subtype 1). Another pattern is characterized by SIB that is invariant—it occurs at elevated levels across all environmental conditions (Subtype 2). These subtypes have important treatment-related implications as reinforcement-based procedures are markedly less effective for Subtype 2 SIB relative to Subtype 1 SIB (Hagopian et al., 2015; Hagopian et al., 2017; Hagopian et al., 2018).

The relative invariance of SIB across distinct environments that defines Subtype 2 is unusual and raises questions about why this occurs. One thought is that the decreased sensitivity of Subtype 2 SIB to alternative reinforcement could reflect differences in establishing operations for SIB, possibly due to differences in the magnitude of sensory reinforcement produced by SIB. Said another way, SIB may produce reinforcing consequences that are extremely powerful for Subtype 2, such that alternative sources of reinforcement cannot compete with the sensory products of SIB (e.g., endogenous opioids; Cataldo & Harris, 1982).

Another hypothesis is that the decreased sensitivity to alternative reinforcement that characterizes treatment-resistant SIB is not specific to that response class alone. Rather, it may reflect impairments in behavioral flexibility associated with decreased sensitivity to changes in environmental events. Individuals with autism spectrum disorders and other neurodevelopmental disorders (i.e., ADHD) tend to engage in repetitive and invariant patterns of responding that are less sensitive to environmental changes, such as extinction, relative to controls (e.g., Johansen et al., 2002; Rodriguez & Thompson, 2015).

Rooker et al. (2019) sought to determine if the apparent insensitivity to environmental changes characterizing Subtype 2 SIB was unique to only that response class, or if other response classes were also characterized by insensitive responding (see Corr & McNaughton, 2012; Hagopian & Ollendick, 1996; Shapiro et al., 1988). To examine this issue, Rooker et al. compared responding on a single-operant task (i.e., pressing a microswitch) under changing reinforcement schedules for three individuals with Subtype 2 SIB relative to three individuals with socially maintained SIB (which is characterized by sensitivity to changing environmental conditions; e.g., Hagopian et al., 2017). They found minimal differences in sensitivity to changing contingencies across individuals and groups—that is, all participants' responding generally appeared sensitive to changes in the environment as evidenced by visual inspection of cumulative records during unsignaled transitions from reinforcement to extinction or progressive ratio schedules. Their results provide preliminary support for the hypothesis that insensitivity of Subtype 2 SIB is unique to that response class only and does not reflect a broader deficit in behavioral flexibility that has generality to other response classes. The purpose of Study 2 was to reanalyze Rooker et al. using the methods described above to further examine the microstructural properties of behavior during operant extinction that might provide insight into the behavioral mechanisms underlying Subtype 2 SIB.

STUDY 2

Data Acquisition and Preparation

Human-operant data reported in Rooker et al. (2019) served as the basis for this reanalysis. A complete description of procedures and individualized modifications are detailed in Rooker et al., but the general approach is described below. Six individuals admitted to an inpatient unit for the assessment and treatment of severe problem behavior served as participants. All participants engaged in SIB and were diagnosed with an IDD (see Table 1 in Rooker et al.). Prior to the experiment proper, Rooker et al. conducted a functional analysis to determine the controlling variables of SIB for each participant; for three participants (ABS10, ABS20, and ABS23), SIB was undifferentiated across the no-interaction and toy play control conditions of the functional analysis commensurate with Subtype 2 SIB. For the other three participants (ABS15, ABS16, and ABS19), SIB was found to be maintained by social positive reinforcement (i.e., attention or access to preferred items).

Procedure

Prior to the start of the operant task, experimenters conducted a paired-stimulus preference assessment to identify highly preferred (HP) and/or MP edibles for use in the experimental analysis described below. Participants were seated at a table across from the experimenter; a microswitch was placed in front of the participant, and a container of food was held out of reach by a second experimenter. First, a minimum of two 5-min, pre-experimental response-establishment sessions were conducted in which experimenters reinforced microswitch presses on a FR-1 schedule with a single piece of food. During the experiment proper, responding for a HP and/or MP edible was evaluated in a series of two-component mixed schedules. Sessions always began with a 5-min FR 1 component followed immediately by either a 10-min extinction component or within-session progressive schedule component (which is not the focus of or included in the present reanalysis). These were mixed schedules because no contingency-correlated stimuli were programmed in this experimental analysis and the transition from reinforcement to extinction was not signaled. A single session was conducted for each two-component mixed schedule. The order of the HP and MP sequences were randomized for participants who experienced both HP and MP conditions. During the reinforcement component, each target response produced one piece of food (FR 1). When the experimenter delivered the reinforcer, they temporarily removed the microswitch. During extinction, the target response did not produce any programmed consequences. Time to consume food during the reinforcement component was included in all analyses below, with the exception of ABS15 (HP and MP). Procedures were individualized for this participant, who received a token on a FR-1 schedule for each target response during the reinforcement interval. Following the extinction component, he exchanged his tokens for the HP or MP edibles in blocks of ten (one unit of food per token).

RESULTS AND DISCUSSION

Band plots depicting individual IRTs as a function of time in reinforcement and extinction components are displayed in Figure 5. During the reinforcement component, there was generally a single, prominent IRT band indicative of recurrent target responding—in other words, there was a clear preponderance of short IRTs around particular, unchanging values. This was especially pronounced in experimental applications for ABS15 HP, ABS15 MP, ABS10 MP, ABS20 HP, ABS20 MP, and ABS23 MP. For example, consider responding from ABS15 HP during the reinforcement component (Figure 5, top left panel)—the band plot indicates that nearly all IRTs here were less than 3 s, with the vast majority occurring at virtually the same value (ca. 2 s). This response pattern suggests that these responses occurred within a single uninterrupted bout of behavior, with no pauses in the target response. Recall that, for ABS15, edible consumption was delayed until the end of the session. Thus, there was no time allocated to reinforcer consumption during this component, which potentially explains the particularly invariant response pattern observed in the reinforcement component.

Extinction produced a marked scattering in the distribution of IRTs (Millenson & Hurwitz, 1961), primarily reflected in a simultaneous quickening of some IRTs (possibly consistent with an extinction burst; Nist & Shahan, 2021), along with a considerable increase in the duration of IRTs for a subset of responses contributing to a decline in overall response rate. As Blough detailed—"In extinction there are not only more and more long IRTs, but an increasing scattering of shorter ones (1963, p. 244)." These longer IRTs correspond to pauses between bouts of responding during extinction. This mixture of short and long IRTs is indicative of responding that occurs in bouts and pauses during extinction. For a number of applications (ABS16 HP, ABS19 MP, ABS10 MP, ABS20 HP, ABS23

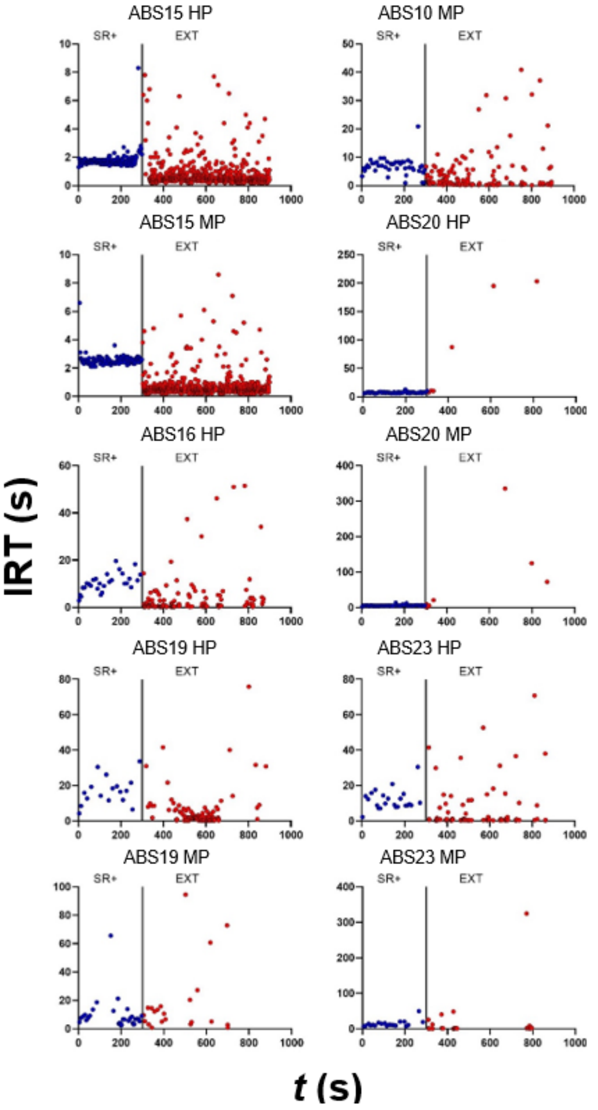

Figure 5. Band Plots for Reinforcement and Extinction Components in Rooker et al. (2019). *Note:* SR+ = reinforcement condition; EXT = extinction condition. Applications with socially maintained SIB and Subtype 2 SIB are in the left column and right columns, respectively.

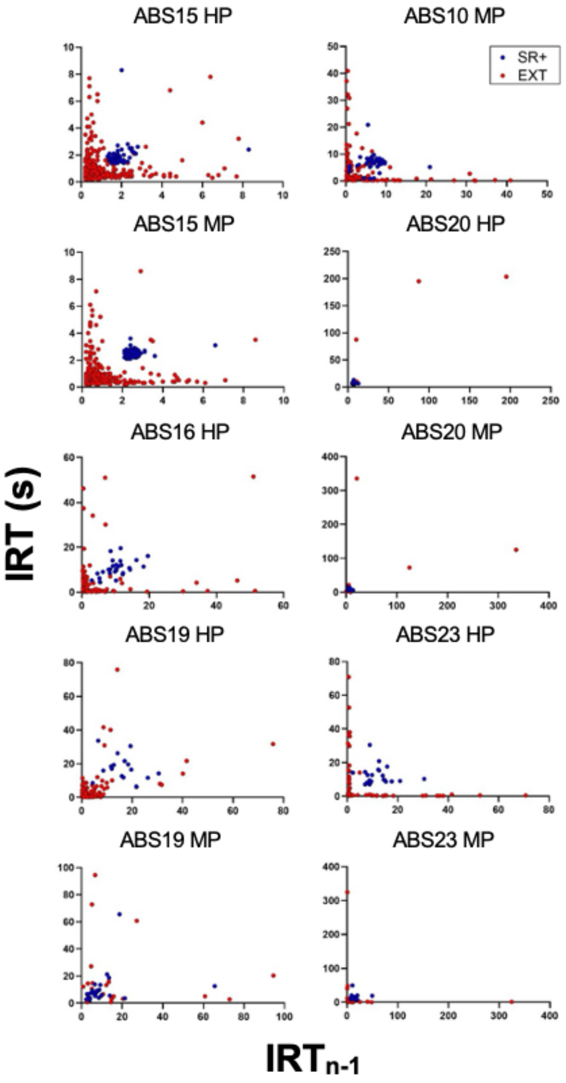

Figure 6. Band Plots for Reinforcement and Extinction Components in Rooker et al. (2019). *Note:* SR+ = reinforcement condition; EXT = extinction condition. Applications with socially maintained SIB and Subtype 2 SIB are in the left column and right columns, respectively.

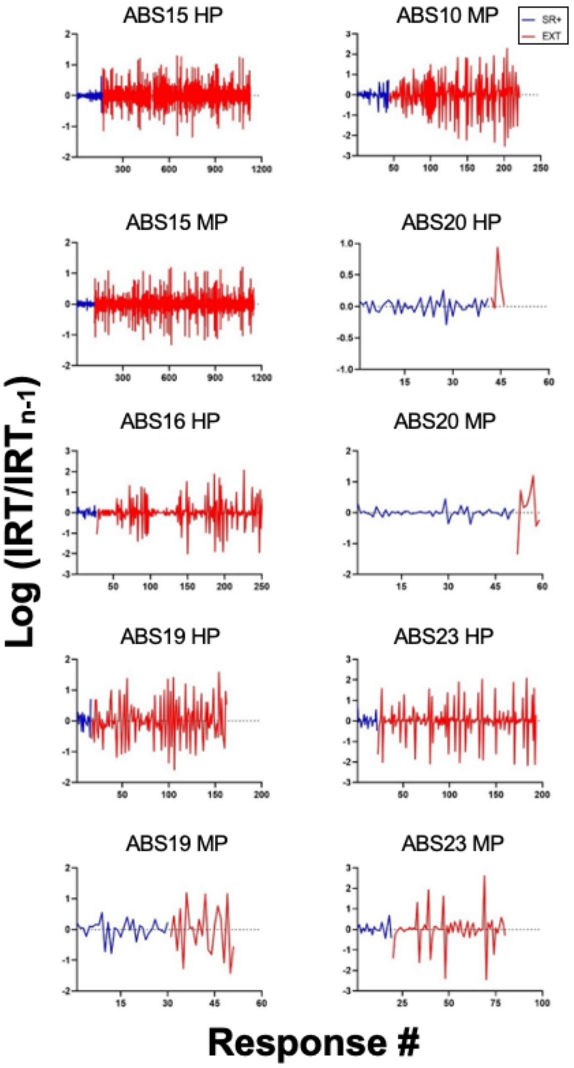

Figure 7. Log Return Plots for Reinforcement and Extinction Components in Rooker et al. (2019). *Note:* SR+ = reinforcement condition; EXT = extinction condition. Applications with socially maintained SIB and Subtype 2 SIB are in the left column and right columns, respectively.

HP, ABS23 MP), there appeared to be within-session changes in these longer IRTs, such that they appear to become successively longer as the time spent in extinction increased—this is consistent with notions that bout-initiation rates may decrease asymptotically during extinction (Cheung et al., 2012).

The highly recurrent response pattern engendered from the FR-1 schedule was evident in the return plots for every participant (Figure 6). Taking ABS15 HP as an example once more, the tight clustering of IRTs during the reinforcement component suggest a highly regular response pattern with minimal variation across responses (Figure 6, top left panel). This pattern suggests that responding during the reinforcement component was not temporally organized into bouts and pauses but occurred stereotypically with slight variation. No such patterns were evident during extinction, as changes in IRTs in the figures going from bottom to top were essentially the same as those going from left to right, and there was symmetry around the main diagonal near the origin

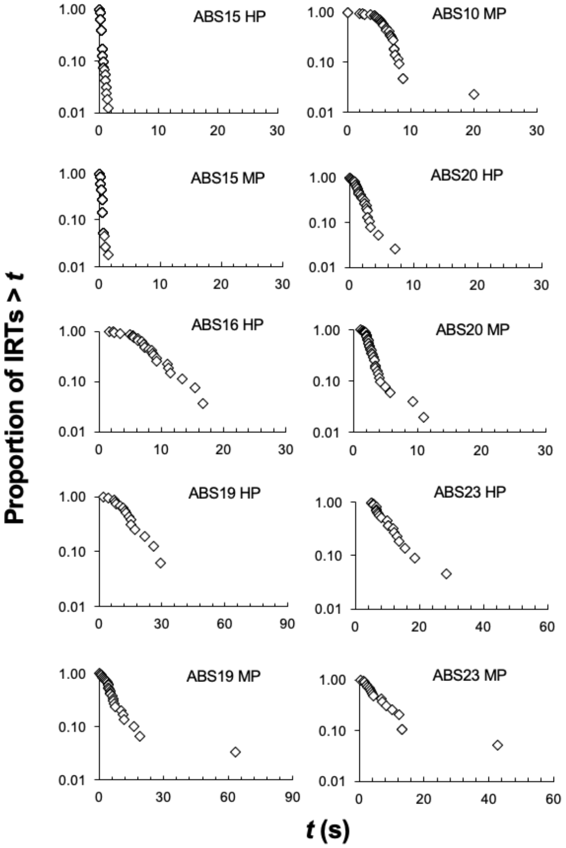

Figure 8. Log Survivor Plots from Reinforcement Component in Rooker et al. (2019). *Note:* Applications with socially maintained SIB and Subtype 2 SIB are in the left column and right columns, respectively.

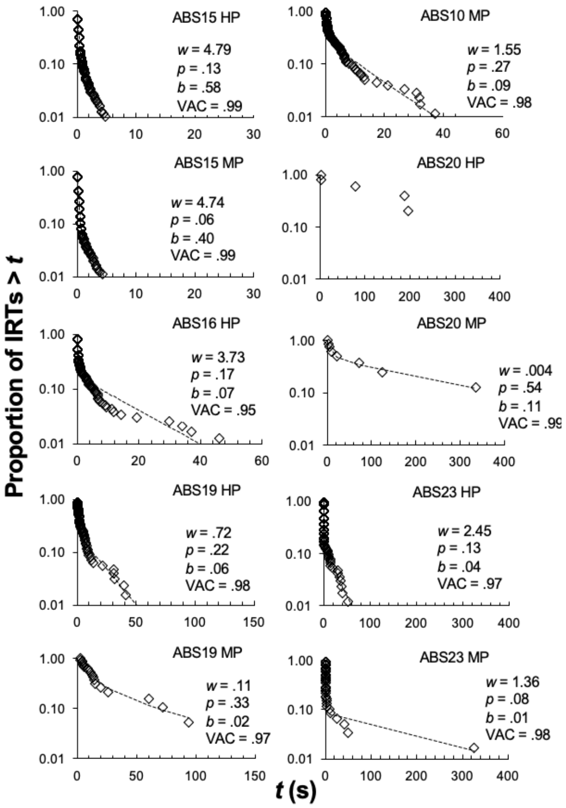

Figure 9. Log Survivor Plots for Extinction Components in Rooker et al. (2019). *Note:* Note. Data points correspond to IRTs; dashed lines correspond to best-fit lines from Eq. 2; w = within-bout response rate (resp/s); p = proportion of responses that are bout initiations; b = bout-initiation rate (resp/s). Applications with socially maintained SIB and Subtype 2 SIB are in the left column and right columns, respectively.

indicative of responding organized into bouts and pauses (Palya, 1992). Thus, the unsignaled transition to extinction produced a change in the temporal distribution of IRTs, but with no clear sequential dependencies or patterns; rather, extinction was associated with a modest shortening of some IRTs along with a significant lengthening of other IRTs. These within-session changes in IRTs during extinction scaled several orders of magnitude (Figure 7). Again, there was little evidence of periodicity or sequential dependence within these plots, although it does appear that the magnitude of relative changes between successive IRTs increased as a function of elapsed time in extinction for ABS10 MP.

Visual inspection of the log survivor plots generated from the reinforcement component for each application indicates that responding did not appear organized into bouts and pauses for most applications (Figure 8). These log survivor plots generally consisted of a single prominent limb indicating an exponential distribution of IRTs. Two exceptions here are ABS19 MP and ABS23 MP, for which there was a single, long IRT forming a right limb of the plot, though the gradually sloped left limb would still indicate a significant blending of short and medium-length IRTs. Transitioning from reinforcement to extinction was associated with a steepening in the slope of the left limbs of the plots (indicating a quickening of shorter IRTs) for a few applications (ABS23 HP, ABS23 MP, ABS16 HP), but the more discernable change across applications was the formation of right limbs indicating a lengthening of some IRTs corresponding to pauses between bouts of button pressing (Figure 9). We subsequently fit Eq. 2 to the log survivor plots of IRTs during the extinction component for each application

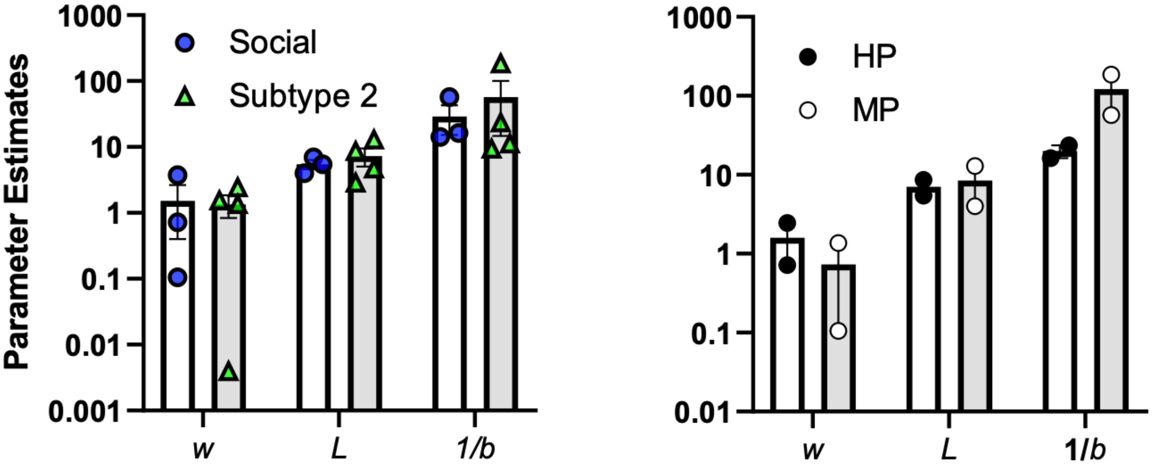

Figure 10. Bout Characteristics of the Target Response during Extinction in Rooker et al. (2019). *Note:* Mean (SEM) parameter estimates from Eq. 2. w = within-bout response rate (resp/s); L = bout length (1/p + 1); 1/b = pause duration (s).

(except for ABS20 HP due to insufficient data points), which provided an excellent account (VAC > 95%) of responding organized into bouts and pauses for each application.

Prior work isolating the behavioral mechanisms of extinction deficits revealed higher rates of bout initiations during extinction among organisms with extinction deficits relative to controls (Brackney et al., 2011). The obtained parameter estimates from Eq. 2 point to minimal differences in the within-bout response rate, bout length, or pause duration of target responding between individuals with socially maintained vs. automatically maintained SIB (Figure 10). Said another way, among individuals with socially versus automatically maintained SIB, there were no apparent differences in the behavioral expression of extinction-induced behavior. These outcomes suggest minimal differences in sensitivity to environmental changes involving extinction between individuals with socially maintained and automatically maintained SIB (Cheung et al., 2012). These findings also add an additional degree of support to the conclusions drawn from Rooker et al. (2019) suggesting that the insensitivity to disruption by alternative reinforcement characteristic of Subtype 2 SIB is specific to that response class alone and is not indicative of a generalized response tendency characterized by a lack of sensitivity to environmental changes—at least, involving extinction—spanning other response classes. A logical and necessary next step in this line of research is to examine sensitivity to changes in the environment involving background reinforcement specifically given this more directly reflects the defining distinction between the subtypes (viz., differential sensitivity of SIB to disruption by alternative reinforcement). For the two cases with transitions to extinction following reinforcement components tested with both HP and MP stimuli (i.e., ABS 19, and ABS 23), target responding during extinction was punctuated by longer pauses following components with MP stimuli relative to HP stimuli (Figure 9), while differences in within-bout response rates and bout length were minimal. This preliminary finding is consistent with results from several basic studies (e.g., Shull, 2004) demonstrating that bout-initiation rates reflect the contribution of reinforcement-related variables, including reinforcer quality, but obviously warrant additional investigation with a larger sample.

RESULTS AND DISCUSSION

There is immense richness and complexity in the temporal dynamics of behavior—the demonstrations above have not even scratched the surface of possibilities, as there are additional dimensions of the target response that are examinable with these techniques (e.g., peak response force; Pinkston & McBee, 2014). This study also contributes to a relatively small empirical base for the study of temporal behavior dynamics in human-operant behavior (Chen et al., 2020; Chen & Reed, 2020, 2021, 2023). Although there was clear heterogeneity in the temporal organization of responses within and across participants, the disruptive effects of unsignaled transitions to extinction were evident in the temporal organization of human-operant performance. Participants' behavior was sensitive to the unsignaled changes in the environment studied via these two-component mixed schedules, as indicated by changes in the temporal organization of target behavior. During the reinforcement component, there was generally a single, prominent IRT band indicative of recurrent target responding. Transitions to the extinction component were marked by changes in the structure of IRTs underlying target responding, indicating a lengthening of longer IRTs corresponding to pauses in-between bouts of activity in addition to a modest shortening of other IRTs corresponding to within-bout responses. Overall, these results indicate that, as an operation, extinction appears to change the temporal organization of behavior, primarily by increasing the duration of some IRTs while leaving shorter IRTs relatively intact. Among individuals with socially versus automatically maintained SIB, there were no apparent differences in the behavioral expression of extinction-induced behavior.

Extinction bursts are another area where analyses of temporal dynamics may provide additional insights into behavioral process. Shahan (2022) recently proposed a quantitative model of extinction bursts based on the temporally weighted matching law (TWML; Shahan & Craig, 2017). This model suggests that behaviors related to reinforcer engagement (i.e., consummatory behaviors) compete for allocation with the behaviors that produce reinforcement (i.e., target responses). When reinforcers are removed in extinction, reinforcer engagement is prevented, resulting in a transient relative shift in behavioral allocation toward the target response (i.e., extinction bursts occur). Afterward, responding decreases as continued extinction decreases the value of target responding. Analyses of temporal dynamics suggest that motoric effects are responsible for within-bout responding, and that transitions to extinction are marked by scattering of within-bout IRTs – resulting in some shorter within-bout IRTs and increasingly longer between-bout IRTs (e.g., Blough, 1963). Brought together, the TWML-based account of extinction bursts and analyses of temporal dynamics suggest that extinction bursts are driven by scattering of within-bout IRTs induced by motoric aspects of the response (i.e., reduced competition for allocation) and the decline in behavior as time progresses in extinction is driven by increasingly longer between-bout IRTs induced by motivational aspects of the response (decreased value for the target response). Thus, analyses of temporal dynamics are consistent with the TWML-based account of extinction bursts and provide further insight into how responding changes over time in extinction.

The potential insights that could be gained in SIB subtypes and extinction bursts are but two of many conceivable examples of how analyses of temporal dynamics could be used to further understanding of the mechanisms underlying behavior. These approaches may supplement response rate as an index of behavioral flexibility and variation, and thus aid in a more complete description of behavior during extinction (Millenson & Hurwitz, 1961; Nist & Shahan, 2021). It is our hope that by providing these examples, future research is dedicated to explore how analyses of temporal dynamics, applied broadly, can supplement molar response rate analyses and contribute to a more complete analysis and understanding of behavior.

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