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CHARACTERIZING RESPONSE–REINFORCER RELATIONS IN THE NATURAL ENVIRONMENT: EXPLORATORY MATCHING ANALYSES

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We assessed problem and appropriate behavior in the natural environment from a matching perspective. Problem and appropriate behavior were conceptualized as concurrently available responses, the occurrence of which was thought to be determined by the relative rates or durations of reinforcement. We also assessed whether response allocation could be accounted for by relative rates or durations of an event not shown to reinforce problem behavior. The effects of the temporal proximity between a response and stimulus and the unit of repeated observations were examined. Results highlighted potentially important reinforcement parameters (e.g., duration) and the time frame in which reinforcement effects might be expected to occur. Although findings are reported for only 1 participant, the purpose of the current study was to assess methodological features of characterizing response–reinforcer relations in the natural environment.

Key words: autism, choice, descriptive analysis, functional analysis, matching law, problem behavior, reinforcement parameters

In recent years, there has been an increased interest in the direct observation of severe problem behavior and presumably functionally equivalent topographies of appropriate behavior under naturally occurring environmental arrangements, or descriptive analysis (e.g., Bijou, Peterson, & Ault, 1968; Iwata, Kahng, Wallace, & Lindberg, 2000). Data from naturally occurring interactions have been expressed as the relationship between relative

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response rates and relative reinforcement rates (e.g., Hoch & Symons, 2007; Symons, Hoch, Dahl, & McComas, 2003). This relationship has been quantified, and is generally known as the *matching law*. The matching law states that relative responding approximately equals, or "matches," relative reinforcement (Herrnstein, 1961). A substantive body of existing research has shown that the matching relation is immutable across a variety of situations (see Davison & McCarthy, 1988, and Pierce & Epling, 1983, for extensive reviews). However, relative reinforcement rates are experimentally programmed in the laboratory, but not in the natural environment. Relations (like matching) would be of questionable utility if those relations were not shown to occur beyond the laboratory. This suggests a few questions that may be answered with data from the natural environment. For example, does the matching relation occur outside of the laboratory? Both foraging data (Houston, 1986) and data on the rates of problem behavior and appropriate behavior exhibited by individuals with developmental disabilities (J. Borrero & Vollmer, 2002) suggest that matching does occur in the natural environment. However, another question must be considered when assessing matching in the natural environment: In what ways should data from the natural environment be conceptualized? Furthermore, under what conditions will various conceptualizations fail to demonstrate the matching relation?

J. Borrero and Vollmer (2002) demonstrated that the matching law could describe the relative response allocation of individuals exhibiting severe problem behavior. The researchers conducted descriptive analyses for 4 participants diagnosed with developmental disabilities. Next, the researchers conducted functional analyses based on the procedure described by Iwata, Dorsey, Slifer, Bauman, and Richman (1982/1994) to identify reinforcers for problem behavior. Relative response allocation during the naturally occurring interactions was then retrospectively assessed as a function of relative reinforcement rates using both the simple matching equation and the generalized matching equation described by Baum (1974).

$$\log\left(\frac{R_1}{R_2}\right) = s\log\left(\frac{r_1}{r_2}\right) + \log b, \tag{1}$$

where R_1 and R_2 represent rates of responding for Response 1 (problem behavior, in the study by J. Borrero & Vollmer) and Response 2 (appropriate behavior, e.g., compliance), respectively; and r_1 and r_2 represent rates for reinforcement for Responses 1 and 2, respectively. In this equation, s represents a sensitivity parameter, and b represents a bias parameter. Using Equation 1, equal relative changes in the independent variable produced equal relative changes in the dependent variable, and this relationship is quantified by the s parameter, which describes changes in relative response rate given a one-unit change in the relative reinforcement ratio (Shull, 1991). The b parameter represents bias, or changes in relative response allocation that cannot be explained by relative changes in reinforcement rate. Bias may occur when one response is associated with a relatively longer delay to reinforcement or when one response requires relatively greater effort to complete. Equation 1 allows the resulting function to be depicted as a straight line when plotted on log–log coordinates and is generally preferred relative to the simple matching equation (Moore, 2008).

When data were pooled for all participants, J. Borrero and Vollmer (2002) found that relative response allocation was well accounted for by relative reinforcer rate. Furthermore, when reinforcers were assumed (i.e., when attention was not shown to be a reinforcer but was included in the analyses) and data were pooled, the percentage of variance accounted for was substantially lower (relative to analyses in which functional reinforcers were assessed). These results illustrate the importance of experimentally identifying reinforcers, as opposed to assuming that ubiquitous social consequences reinforce problem and appropriate behavior in the natural environment.

The study by J. Borrero and Vollmer (2002) is limited, however, in at least three ways. First, the researchers considered a response to have been reinforced if the event followed that response within 10 s. As noted by the authors, this was an arbitrary decision and served as a starting point from which further analyses might emerge. However, the identification of a matching relation during naturally occurring interactions may be determined in part by the criterion used to consider a response "reinforced." Second, for 3 of 4 participants, the matching relation was assessed as a single observation. However, the extent to which matching occurs at a more molecular level (e.g., in 5-min observation periods) may not be consistent with relations observed using larger units of analysis (e.g., 1 hr) in the context of aggregate analyses.

It may also be important to take other metrics of behavior into account (e.g., duration). The measurement strategies adopted in applied settings are often determined by the nature of the response and the reinforcer. For example, some individuals may engage in tantrums at a low rate, but for clinically significant amounts of time. Similarly, reinforcement rate may be very low, whereas duration of reinforcement may be considerable. In these cases, duration may play a crucial role in describing response–reinforcer relations. The importance of duration measures was illustrated by Conger and Killeen (1974), who assessed the allocation of undergraduates' attention in a human-operant laboratory setting based on programmed reinforcement rates delivered by confederates. Each participant completed a 30-min discussion during which confederates delivered statements of agreement according to independently programmed variable interval (VI) schedules. Data for 5 participants were aggregated, divided into 5-min periods of observation, and assessed using the following equation:

$$\frac{T_1}{T_1 + T_2} = \frac{r_1}{r_1 + r_2}, \tag{2}$$

where T_1 and T_2 represent the duration allocated to Responses 1 (talking to Confederate 1 in the study by Conger and Killeen) and 2 (talking to Confederate 2), respectively, and r_1 and r_2 are as described in Equation 1. Results indicated that relative durations of response allocation matched relative rates of reinforcement, but only during the last 5 min of the discussion. That is to say, relative response allocation was more likely to match relative reinforcement rates when the reinforcement contingencies had been in place for a longer period of time. In addition to the simple matching equation used by Conger and Killeen, prior research has involved the logarithmic transformation of Equation 3, or, more formally,

$$\log\left(\frac{T_1}{T_2}\right) = s \log\left(\frac{r_1}{r_2}\right) + \log b, \tag{3}$$

where the terms in Equation 3 are the same as those described in previous equations. Although Conger and Killeen did not evaluate Equation 3, there are several important contributions from this study. Of particular importance is the finding that the relative duration of time spent talking to confederates was controlled by relative rates of agreement delivered by those confederates.

Oliver, Hall, and Nixon (1999) used variations of these equations to describe the problem behavior and communicative behavior exhibited by an individual diagnosed with Down syndrome. Descriptive data were assessed as follows:

$$\frac{T_1}{T_1 + T_2} = \frac{t_1}{t_1 + t_2}, \tag{4}$$

where T_1 and T_2 are as described in Equation 3, and t_1 and t_2 represent the duration of reinforcement received for responses T_1 and T_2, respectively. In addition, Oliver et al. adapted the generalized matching equation (Equation 1) in the following expression:

$$\log\left(\frac{T_1}{T_2}\right) = s \log\left(\frac{t_1}{t_2}\right) + \log b, \tag{5}$$

where T_1, T_2, t_1, t_2, s, and b are as described previously. An analysis of 8 hr of descriptive data demonstrated that Equation 5 accounted for 46% of the variance.

Given the nature of response–stimulus relations in uncontrolled environments, it is possible that one of the aforementioned equations differentially accounts for more of the variance in relative response allocation (J. Borrero, Crisolo, et al., 2007). For example, it is possible that some reinforcers (e.g., escape from instructional demands) better account for relative response allocation when expressed as duration of reinforcement—in which case, model comparisons may suggest critical variables to target in subsequent treatment evaluations (J. Borrero, Crisolo, et al., 2007). In addition, exploratory analyses may guide the characterization of response–reinforcer relations in the natural environment.

At present, there have been no such comparative computational analyses of matching conducted for naturally occurring interactions and individuals who exhibit severe problem behavior. Therefore, the purpose of the current investigation was to assess some of the methodological nuances involved in characterizing behavior–response relations in the natural environment using various matching equations. To do so, we assessed three aspects related to the computations using data from 1 participant: (a) the extent to which matching would occur when behavior was assessed in repeated 5- or 10-min bins, (b) the extent to which matching would occur when three contiguity criteria for a reinforced response (1, 5, or 10 s) were assessed separately, and (c) the extent to which characterizing behavior and reinforcement in terms of their rate or duration would influence determinations of matching. As a systematic replication of prior research (J. Borrero & Vollmer, 2002), descriptive data were also assessed when attention was presumed to be a reinforcer to determine whether spurious matching would occur.

Method

Participant

One individual diagnosed with developmental disabilities participated. Bruno[1] was an 11-year-old boy diagnosed with autism. Bruno's problem behavior consisted of aggression (i.e., hitting, kicking, biting, or pinching), disruptive behavior (throwing objects, hitting or kicking objects, or property destruction), self-injurious behavior (SIB; biting himself, hitting himself, or hitting his head on objects), and inappropriate vocalizations (high-pitched vocalizations or screaming). Bruno's appropriate behavior consisted of compliance with instructions, and appropriate vocal or nonvocal (e.g., gestural) requests for a break or tangible items.

Sequence of Events

Descriptive Analysis and Setting. Descriptive data were gathered for Bruno using methods described by C. Borrero and Borrero (2008). Observers used a computerized data collection system to record three potential reinforcers (instruction termination, access to tangibles, and attention), problem behavior (previously defined), appropriate behavior (previously defined), and potential establishing operations (i.e., instructional demands, restricted access to tangibles or edibles, and periods of low attention). The descriptive analysis was conducted prior to the functional analysis to capture behavior in the natural environment prior to exposure to experimental contingencies. Attention was defined as physical or verbal interaction between the participant and staff members. Instruction termination was defined as the absence of discrete instructions for a period of at least 3 s, or the absence of instructions if the participant disengaged from a previously specified task for at least 3 s. Access to tangibles was defined as the availability of items or activities and the absence of denied requests for items or activities. Potential reinforcers and potential establishing operations were recorded as duration measures, whereas instances of problem behavior and appropriate behavior were recorded as frequency measures. Descriptive observations were conducted once a day, one to two times per week, during regularly scheduled activities. Observations were conducted in the participant's classroom at a private school specializing in the education of individuals with developmental and emotional disabilities. Observations were equally spaced across academic activities, snack time, and leisure time. Data were collected until at least 45 instances of problem behavior were observed (for a total of 134.5 min of observation). A teacher and a classroom aid were present during interactions; however, Bruno worked primarily with the same teacher during all observations.

Functional Analysis. Bruno's problem behavior was exposed to functional analyses[2] similar to those described by Smith and Churchill (2002). Two separate functional analyses were conducted to determine whether

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1 Descriptive data for Bruno were previously summarized in J. C. Borrero, Francisco, Haberlin, Ross, and Sran (2007) and C. S. W. Borrero and Borrero (2008). Matching analyses were not conducted in either the study by J. C. Borrero et al. or the study by C. S. W. Borrero and Borrero.

2 Functional analysis data for Bruno were previously summarized in J. Borrero, Francisco, et al. (2007) and presented in C. Borrero and Borrero (2008).

experimental contingencies placed on one set of topographies would influence the frequency with which a second topography of behavior occurred. In the first analysis, experimenters applied contingencies to aggression, disruption, and SIB but not to inappropriate vocalizations. In the second analysis, experimenters applied contingencies to inappropriate vocalizations but not to aggression, disruption, or SIB. The purpose of this two-phased assessment was to determine whether inappropriate vocalizations reliably preceded more severe problem behavior. For the purposes of the current investigation, the objective of the two-phased functional analysis was to empirically identify reinforcers for aggression, disruption, and SIB in one assessment, and those for inappropriate vocalizations in a second assessment.

Interobserver Agreement

Interobserver agreement was assessed by having a second observer simultaneously but independently record data on problem behavior, appropriate behavior, potential establishing operations, and potential reinforcers. Data were calculated using the method of partial agreement within intervals (Iwata, Pace, Kalsher, Cowdery, & Cataldo, 1990). Each observation was divided into 10-s intervals, and agreement between both observers was assessed across each interval. The smaller number of recorded responses in each interval was divided by the larger number of recorded responses, and all values were averaged for the entire observation. Interobserver agreement data were collected for 26% of descriptive analysis observations. Agreement averaged 89.5% for attention (range, 69%–100%), 87% for escape from demands (range, 80%–99%), and 97.7% for access to tangible items (range, 97% –98%). Agreement for problem behavior was 100% and agreement for appropriate behavior was 97.8% (range, 86.1%–100%). Interobserver agreement was assessed during 23% of the functional analysis sessions, and agreement for problem behavior averaged 99.3% (range, 92% –100%).

Data Preparation

All descriptive observations (a total of 135.5 min) were partitioned into 5-min bins to permit repeated measurement and assessment of the matching relation. Presumably, because it has a bearing on data analysis, partitioning the entire descriptive observation into smaller bins should be functionally equivalent to conducting 5- or 10-min descriptive observations. However, this is a matter that can be concluded only by analyses specifically designed to assess this supposition.

Some bins were longer than 5 min and some bins were shorter than 5 min because not all descriptive observations were evenly divisible by 5. When portions of descriptive data were shorter than 5 min, segments of time greater than 150 s were partitioned into a separate bin, whereas segments of time shorter than 150 s were added to the previous bin. Overall, 26% of bins were longer than 5 min and 4% of bins were shorter than 5 min.

Once partitioned, response and reinforcement rates were determined for each bin. In addition, response and reinforcement durations were determined for each bin. If a response occurred at the end of a bin and a reinforcer was presented at the beginning of the next bin, that response was not considered reinforced. This would be similar to the cessation of data collection at the completion of a 5-min observation, only to observe the presentation of a reinforcer. We also evaluated three time windows in which an event was considered to be a reinforcer (i.e., 1, 5, and 10 s) using Equations 1 and 5. For example, if problem behavior was observed in a 5-min bin and a reinforcer was presented 4 s later, the response would *not* be considered reinforced using the 1-s criterion but would be considered reinforced using the 5-s and 10-s criteria.

Next, the previously described sequence was repeated using 10-min bins. When portions of descriptive data were shorter than 10 min, segments longer than 300 s were partitioned into a separate bin, whereas segments shorter than 300 s were added to the previous bin. Overall, 31% of the bins were longer than 10 min and 31% of the bins were shorter than 10 min. Although the time windows selected for the present analyses were no less arbitrary than those used in prior work (e.g., J. Borrero & Vollmer, 2002), a wider range of values was selected to further assess the differences between models using variations on the criterion for a reinforced response.

Because the target responses were recorded as frequency measures, the frequency of behavior was equal to the duration of behavior. Thus, analyses conducted using Equations 2 and 3 are not reported, but they are available from the authors upon request. To transform frequency measures of behavior into duration measures, the time required to emit *x* instances of behavior was determined. For example, if in one 5-min bin Bruno emitted five instances of problem behavior and eight instances of appropriate behavior, it was assumed that Bruno spent 5 s engaging in problem behavior and 8 s engaging in appropriate behavior.

To reiterate, analyses were conducted in 5-min bins and a response was considered reinforced if a functional reinforcer was available within 1, 5, or 10 s, using Equations 1 and 5 (resulting in six analyses). These analyses were then repeated using 10-min bins, yielding a total of 12 analyses using functional reinforcers. Furthermore, the same analyses were conducted using a nonfunctional reinforcer (attention), producing an additional 12 analyses.

Results

Functional Analysis

Results of the functional analysis can be found in C. Borrero and Borrero (2008). Results suggested that Bruno's problem behavior was sensitive to both access to tangible items and escape from instructional demands but not to attention.

Matching Analyses

For all figures, R_1 and R_2 represent the rate of problem behavior and appropriate behavior, respectively, and r_1 and r_2 represent rate of reinforcement for problem behavior and appropriate behavior, respectively. T_1 and T_2 represent the duration of problem behavior and appropriate behavior, respectively, and t_1 and t_2 represent duration of reinforcement for problem behavior and appropriate behavior, respectively. In all figures, the broken diagonal line represents perfect matching and the solid line (when depicted) is the best-fit line.

Figure 1 displays matching analyses when Equations 1 (left column) and 5 (right column) were used to evaluate performance across 5-min bins.

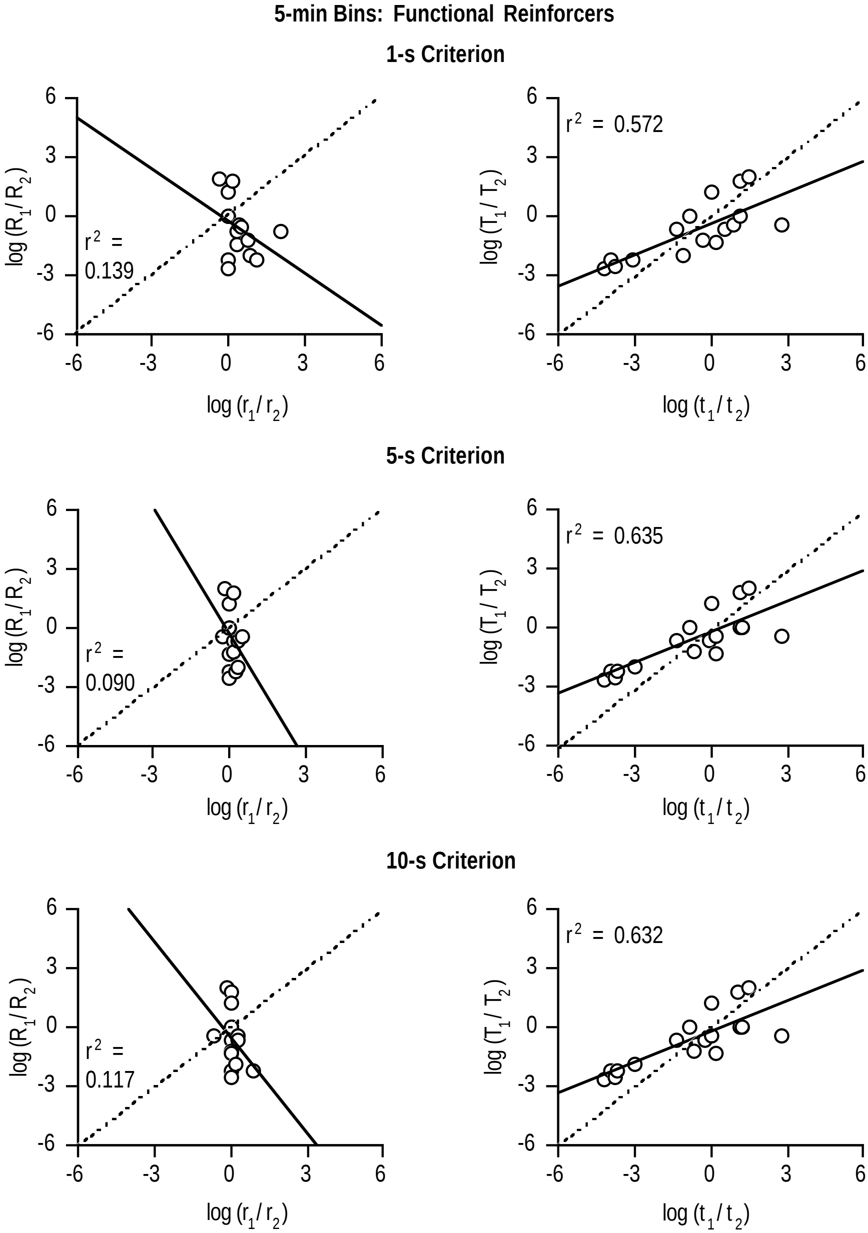

Figure 1. Results of matching analyses with functional reinforcers using Equations 1 (left column) and 5 (right column), during 5-min bins. In the top row are analyses conducted using the 1-s criterion, in the middle row are analyses conducted using the 5-s criterion, and in the bottom row are analyses conducted using the 10-s criterion. The dashed diagonal line represents perfect matching, and the solid line is the best-fit line.

When the 1-s criterion was applied using Equation 1, the spread of relative reinforcement values was very narrow and very little of the variance was accounted for (r^2 = .14). The same general finding was observed when the 5-s (r^2 = .09) and 10-s criteria (r^2 = .12) were applied to Equation 1. When the 1-s criterion was applied to Equation 5, more variance was accounted for (r^2 = .57). However, there was considerable bias (*b* = –.36) toward appropriate behavior. Similar to prior evaluations of human responding (e.g., Hoch & Symons, 2007), undermatching occurred (*s* = .52), indicating that changes in relative responding were not as large as changes in relative reinforcement (Madden, Peden, & Yamaguchi, 2002). Table 1 shows that undermatching occurred across all evaluations of Equation 5 (*s* values < 1). Once again, when the 5-s criterion was applied (middle left panel), a larger proportion of the variance was accounted for (r^2 = .64) relative to evaluations using Equation 1. As shown in Table 1, considerable bias (*b* = –.25) for appropriate behavior was observed. When the 10-s criterion was applied using Equation 5, the proportion of the variance was .63 (bottom left panel), with notable bias (*b* = –.24).

Table 1
Bias and Sensitivity Estimates for Equations 1 and 5 With Functional Reinforcers

Observation Bin	Criterion for Reinforcement	Equation 1			Equation 5		
		S	*b*	r^2	*S*	*b*	r^2
5 min	1 s	− 0.87	− 0.21	0.14	0.52	− 0.36	0.57
5 min	5 s	− 2.12	− 0.35	0.09	0.52	− 0.25	0.64
5 min	10 s	− 1.61	− 0.55	0.12	0.52	− 0.24	0.63
10 min	1 s	− 0.28	− 0.34	0.01	0.48	− 0.18	0.61
10 min	5 s	1.78	− 0.30	0.11	0.49	− 0.12	0.64
10 min	10 s	1.57	− 0.15	0.12	0.60	0.13	0.80

Figure 2 displays data obtained from Equations 1 and 5 when data were analyzed across 10-min bins. When the 1-s reinforcement criterion was applied using Equation 1 (top left panel), a narrow spread of relative reinforcement values was observed and Equation 1 did not account for much of the variance (r^2 = .01). The 5-s and 10-s criteria provided similarly weak outcomes (r^2 = .11 and r^2 = .12, respectively). However, the top right panel indicates that applying the 1-s criterion to Equation 5 accounted for a larger proportion of the variance (r^2 = .61), although there was considerable bias (*b* = -.18). The middle right panel displays data obtained when the 5-s criterion was applied to Equation 5. In this analysis, Equation 5 accounted for a large proportion of the variance (r^2 = .64); additionally, there was less bias (*b* = –.12). The bottom right panel displays data obtained when the 10-s criterion was applied using Equation 5. In this analysis, relative durations of responding matched relative durations of reinforcement (r^2 = .80).

Figures 3 and 4 display data obtained using a presumed reinforcer, attention. Figure 3 displays results obtained when data were partitioned into 5-min bins. Equations 1 (left panel) and 5 (right panel) were assessed. When the various criteria for reinforcement were applied to Equation 1, coefficients of determination were low (r^2 = .01, r^2 = .21, and r^2 = .23, respectively). However, Equation 5 accounted for comparatively more of the variance.

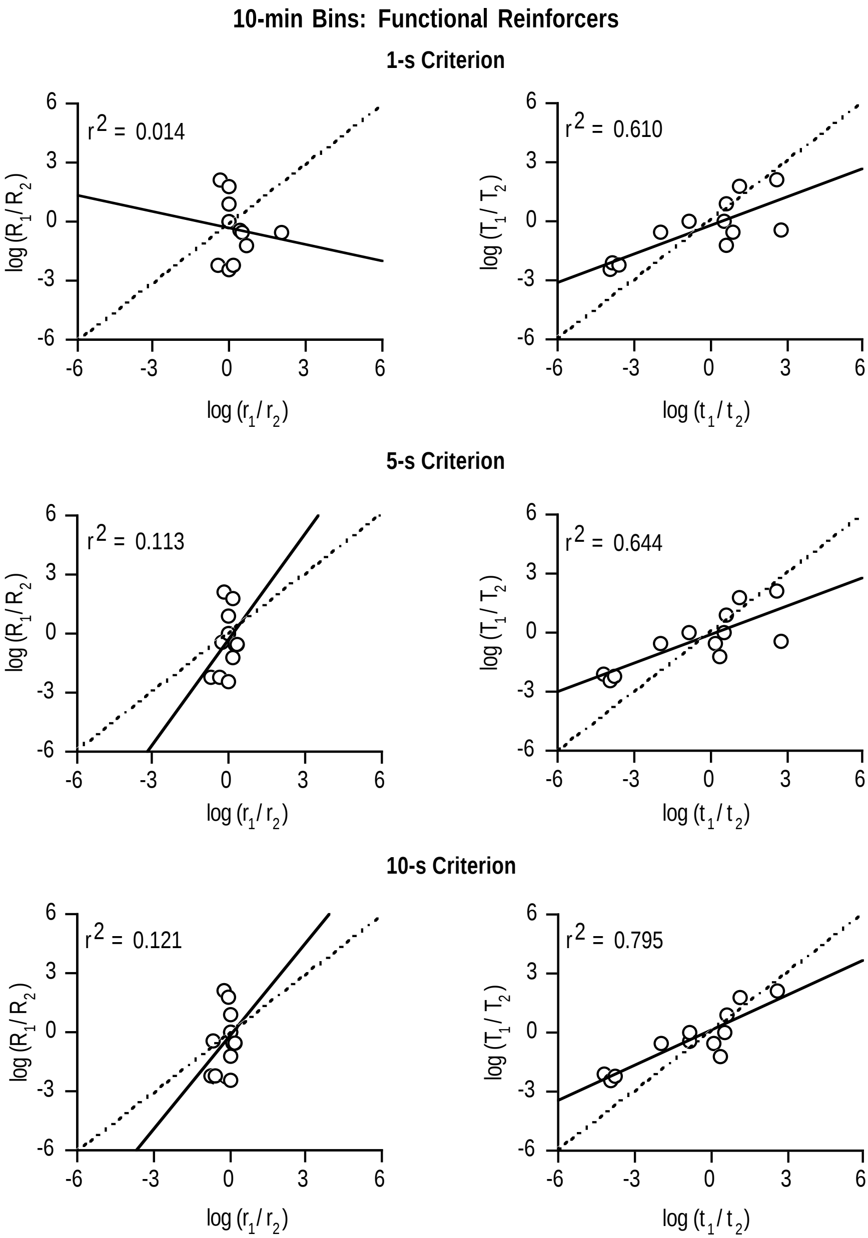

Figure 2. Results of matching analyses with functional reinforcers using Equations 1 (left column) and 5 (right column), during 10-min bins. In the top row are analyses using the 1-s criterion, in the middle row are analyses using the 5-s criterion, and in the bottom row are analyses using the 10-s criterion. The dashed diagonal line represents perfect matching, and the solid line is the best-fit line.

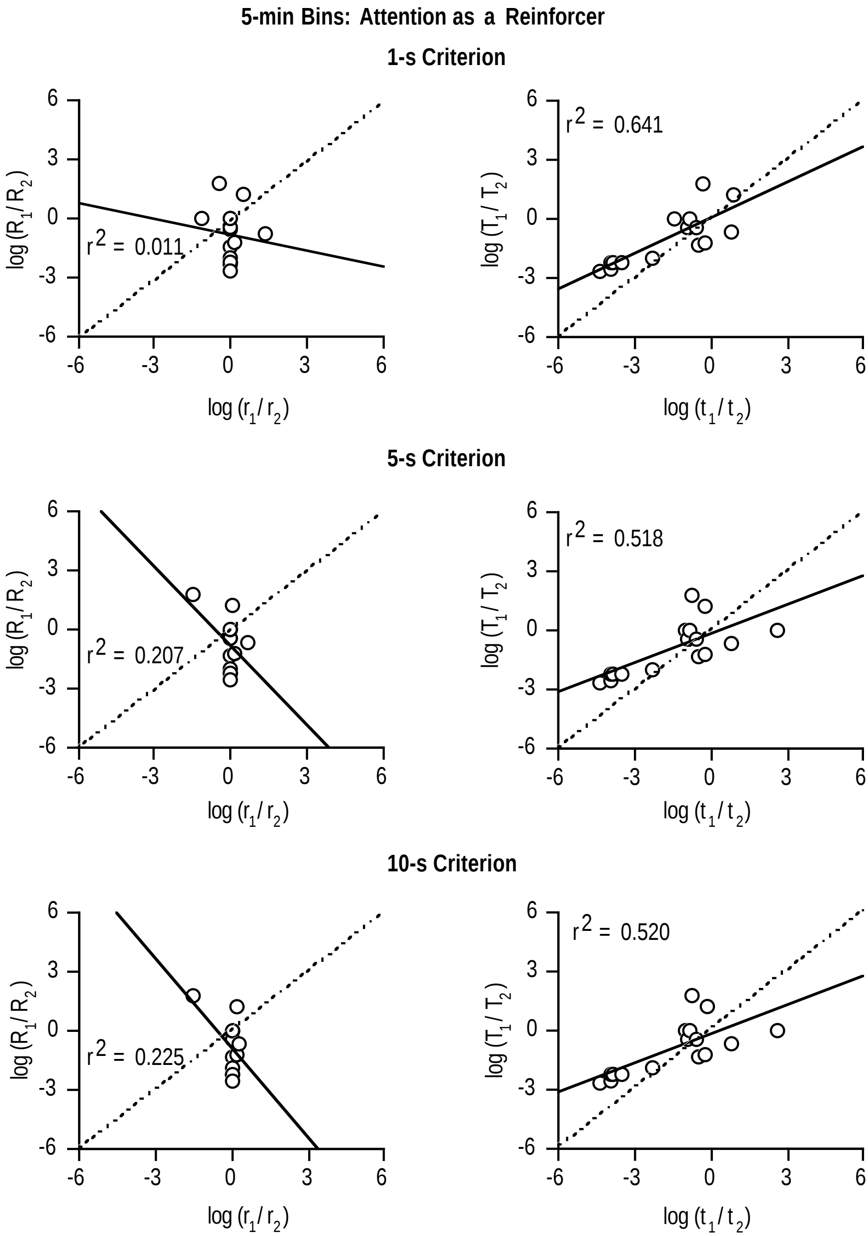

Figure 3. Results of matching analyses with attention as a presumed reinforcer using Equations 1 (left column) and 5 (right column), during 5-min bins. In the top row are analyses conducted using the 1-s criterion, in the middle row are analyses conducted using the 5-s criterion, and in the bottom row are analyses conducted using the 10-s criterion. The dashed diagonal line represents perfect matching, and the solid line is the best-fit line.

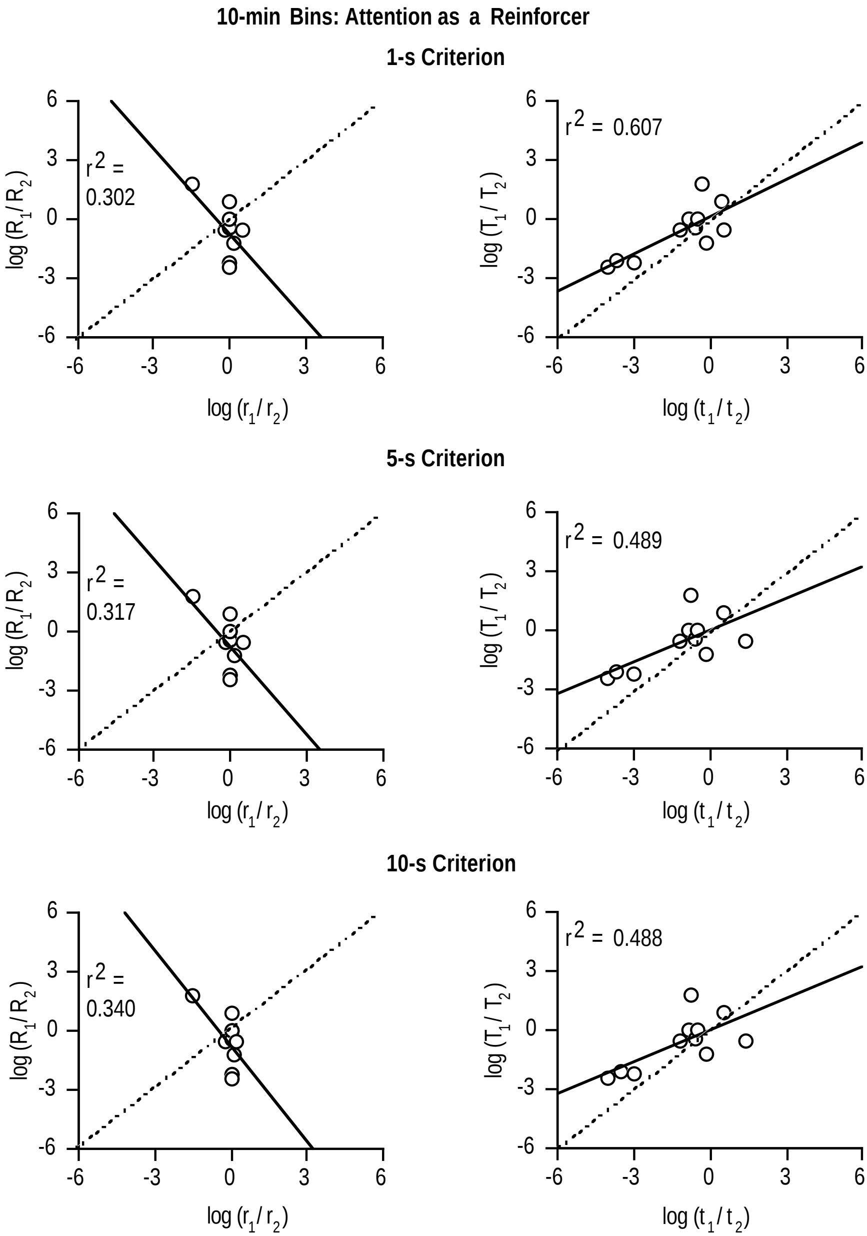

Figure 4. Results of matching analyses, with attention as a presumed reinforcer using Equations 1 (left column) and 5 (right column), during 10-min bins. In the top row are analyses conducted using the 1-s criterion, in the middle row are analyses conducted using the 5-s criterion and in the bottom row are analyses conducted using the 10-s criterion. The dashed diagonal line represents perfect matching, and the solid line is the best-fit line.

Figure 4 displays data obtained when data were analyzed across 10-min bins, Equations 1 and 5 were used, and attention was presumed to be a reinforcer. The top panel displays data obtained using a 1-s reinforcement criterion, the middle panel displays data obtained using the 5-s criterion, and the bottom panel displays data obtained using the 10-s criterion. In sum, results of these analyses are very similar to those previously reported, in that the greatest percentage of variance accounted for was obtained using Equation 5, even though attention was not identified as a reinforcer for Bruno's problem behavior.

Discussion

The purpose of the current investigation was to explore some nuances of data analysis procedures as they relate to evaluations of matching in the natural environment, using data from 1 participant. We evaluated whether a parameter other than reinforcer rate might better account for relative response allocation and to determine whether matching would occur if an arbitrary event (attention) was incorporated into the analyses. In other words, we sought to determine the most informative method of characterizing behavior–environment relations in the natural environment using variations of the matching law. This exploratory research suggests that the way in which behavior–environment relations are conceptualized (at the point of data preparation and analysis) may impact one's ability to capture matching in the natural environment.

The matching law assumes that relative response rate is a function of some parameter of relative reinforcement value. Early research demonstrated that factors such as relative reinforcement amount (Catania, 1963) and relative reinforcement immediacy (Chung & Herrnstein, 1967) affected relative response allocation. Less clear from these early analyses is whether relative reinforcement duration is an important measure of value. Results from the current investigation suggest that duration is in fact an important parameter. Specifically, results indicated that matching was more likely when behavior and reinforcement were characterized in terms of Equation 5 relative to Equation 1. Notable is the considerable bias (*b*) toward appropriate behavior summarized in Table 1. This bias may be explained at least in part by more fine-grained analyses of the data. For example, there were several instances in which comparable levels of problem and appropriate behavior were observed, but appropriate behavior was associated with greater durations of reinforcement. Similarly, there were also cases in which comparatively fewer instances of appropriate behavior occurred within a single bin, but reinforcement durations for both problem behavior and appropriate behavior were similar. As evaluated in the present study, one cannot determine the precise role of proximate events on subsequent behavior. However, further experimental analyses of these interactions (Davison & Baum, 2003) may prove fruitful. For example, these analyses may suggest that appropriate behavior persists during contingencies that favor problem behavior *when preceded by* relatively rich schedules that favor appropriate behavior. These types of analyses would add to research demonstrating the influence of previous contingencies on current response rates (e.g., Doughty et al., 2005; Okouchi, 2007).

It is important to note that one of the reinforcers for Bruno's problem behavior was escape from instructional demands. It may be the case that the *duration* of escape was more important than the rate of escape, for Bruno. However, the parameter of reinforcement that best describes response allocation might differ across response function, or individuals. For example, Hoch and Symons (2007) found that relative rates of responding closely matched relative rates of attention for 2 out of 3 participants. Likewise, J. Borrero, Crisolo, et al. (2007) found that Equation 1 accounted for a considerable portion of the variance in levels of attending for 7 of 9 participants when statements of agreement were used as the reinforcer. It may be that escape and access are better conceptualized in terms of duration, whereas attention is better conceptualized in terms of rate. However, in the current investigation, there was less variability in relative reinforcement rates and more variability in relative durations of reinforcement.

Results of the current investigation also indicated that less rigorous criteria are more likely to produce matching. That is to say, larger observation units (e.g., 10 min) may permit relative response allocation to approach steady state, and larger windows of "counting" an event as a reinforcer may capture more relevant environmental events. For example, larger coefficients of determination were obtained when matching was evaluated using Equation 5, when data were partitioned into 10-min bins, and when data were evaluated using the 10-s criterion to count an event as a reinforcer. This finding is not surprising, as the unit of analysis was increased. Baum and Rachlin (1969) noted that it is useful to view behavior over time, rather than focusing on discrete responses. These results may also illustrate what Skinner (1935) referred to as the "natural lines of fracture" (p. 40). In other words, the extent to which order is revealed may depend on both the characterization of behavior (in terms of its rate or duration) and the unit of analysis. An objective of the present study was to illustrate a method by which researchers may identify order in the behavioral stream, in the natural environment.

Results of the current investigation also support previous literature on spurious matching (St. Peter et al., 2005). Spurious matching occurs when responding is correlated with environmental events that do not function as reinforcers. Although St. Peter et al. found that spurious matching occurred for all 3 participants, results of the current investigation were not as consistent: Spurious matching was more likely when data were analyzed across 5-min bins as opposed to 10-min bins. These results suggest that less rigorous analyses (as defined previously), which were more likely to produce matching, were also less likely to produce spurious matching.

These results should be viewed in light of several limitations. Because results for only 1 participant were assessed under relatively specific environmental conditions, the internal validity and external validity of these analyses remain unclear. However, it seems less important that the same or even similar results are obtained with additional participants. For example, additional analyses may show that relative reinforcement rate explains more of the variance than relative duration of reinforcement (a finding opposite to the one reached in the present study). If relative reinforcement rate was shown to be a more useful explanatory variable, our understanding of this relation would still be improved, and the results could be used to inform behavioral assessment and intervention. That is, methods used in the present study could identify parameters of reinforcement that may be important to consider when making treatment recommendations. Treatments could involve the manipulation of reinforcement rate if Equation 1 better accounts for relative response allocation, and treatments could involve the manipulation of reinforcement duration if Equation 5 better accounts for relative response allocation.

To be considered a reinforcer, an event had to be present within 1, 5, or 10 s of either appropriate or problem behavior. For example, if escape from instructional demands occurred and Bruno emitted SIB while escape from instructional demands was in place, the SIB was considered "reinforced" if escape continued following the response. This method can be contrasted with one in which an event is only "counted" as a reinforcer if it was *absent* prior to the occurrence of SIB and *presented* subsequent to SIB. We do not wish to speculate on which of these methods best captures response–stimulus relations in the natural environment, as doing so goes beyond the primary objectives of this study. As Vollmer and Samaha (2006) suggested, identification of contingent relations in the natural environment is a very difficult endeavor. Sufficient experimental evidence seems to exist to support the two conceptualizations just described (e.g., Iwata, 1987). The decision to use the former method was based on applications from previously published works that have shown evidence for the matching relation in the natural environment (e.g., J. Borrero & Vollmer, 2002; St. Peter et al., 2005). This does, however, suggest an avenue for further computational analyses in which evaluations of contiguous relations are compared to those in which an event must follow (but not precede) behavior to be considered a reinforcer.

As mentioned previously, we did not include Equations 2 and 3 in the comparative analyses because our focus was on the generalized matching equation, which has been shown to better account for deviations from strict matching and is considered among the more modern expressions of the matching law (McDowell, 2005). Additionally, analyses using Equation 3 were identical to those using Equation 5 (given that the duration of behavior was identical to the rate of behavior). Future research could evaluate Equations 1, 3, and 5 when responses can be conceptualized in terms of both duration and rate (e.g., responses such as elopement, tantrums).

Additionally, it is important to note that evaluations of matching in the natural environment are correlational (i.e., we cannot conclude that changes in reinforcement duration caused changes in response rate). Thus, although Equation 5 accounted for a relatively large proportion of the variance, it is unclear whether changes in relative response durations were functionally related to changes in relative reinforcer durations. However, the results suggest that experimenters could shift response allocation from problem behavior to appropriate behavior by experimentally manipulating the duration of escape in favor of appropriate behavior.

The current investigation incorporated repeated measurement, a broader range of matching equations than has been previously assessed in studies of matching in the natural environment, and a wider array of values to capture potential reinforcement contingencies. However, questions remain regarding the interactive role of reinforcement parameters, such as rate, duration, quality, and delay. In the current investigation, we did not collect data on the aversiveness of demands or the quality of escape from those demands; however, these variables may have played a crucial role in response allocation. Additionally, the extent to which Bruno received escape and access to preferred items or activities outside of session may also have influenced relative response allocation. However, those data were not available. Thus, future research may be designed to assess concatenated matching equations (e.g., Davison & Hogsden, 1984; Miller, 1976; Vollmer & Bourret, 2000) in which two or more parameters of reinforcement are assessed as variables responsible for response allocation.

Data from the current investigation indicate that Equation 5 accounted for relatively more of the variance in responding relative to Equation 1, for 1 participant. The present data provide further support for the ubiquity of matching and, in particular, matching in the natural environment. However, the current data also illustrate that this finding may be driven in part by the particular model of matching selected. If we had assessed the present data solely in terms of Equation 1, we could only report a failure to replicate. However, additional analyses produced results that are more consistent with previous matching analyses that incorporated relative reinforcement and response durations (Oliver et al., 1999). Thus, model selection, the methods used to partition behavior, and the methods used to characterize reinforcement may all influence evaluations of matching in the natural environment.

The present investigation suggests that applied researchers must grapple with many conceptual, theoretical, and computational matters to better understand matching in uncontrolled environments. However, from a practical perspective, these complex analyses may not be required. Rather, clinicians need only recognize how (potential) reinforcers are arranged in the natural environment and then rearrange those events to favor the occurrence of appropriate behavior. Analyses of the sort described in this study and related work (C. Borrero, Vollmer, Borrero, & Bourret, 2005) may simply quantify these relations within a conceptual system that is consistent with behavior analysis research and practice.

References

BAUM W. M., & RACHLIN, H. C. (1969). Choice as time allocation. *Journal of the Experimental Analysis of Behavior, 12,* 861–874.

BAUM W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior, 22,* 231–242.

BIJOU, S. W., PETERSON, R. F., & AULT, M. H. (1968). A method to integrate descriptive and experimental field studies at the level of data and empirical concepts. *Journal of Applied Behavior Analysis, 1*, 175–191.

BORRERO, C. S. W., & BORRERO, J. C. (2008). Descriptive and experimental analyses of potential precursors to problem behavior. *Journal of Applied Behavior Analysis, 41,* 83–96.

BORRERO, C. S. W., VOLLMER, T. R., BORRERO, J. C., & BOURRET, J. (2005). A method for evaluating parameters of reinforcement during parent–child interactions. *Research in Developmental Disabilities, 26*, 577–592.

BORRERO, J. C., CRISOLO, S. S., TU, Q., RIELAND, W. A., ROSS, N. A., FRANCISCO, M. T., ET AL. (2007). An application of the matching law to social dynamics. *Journal of Applied Behavior Analysis, 40*, 589–601.

BORRERO, J. C., FRANCISCO, M. T., HABERLIN, A. T., ROSS, N. A., & SRAN, S. K. (2007). A unit price evaluation of severe problem behavior. *Journal of Applied Behavior Analysis, 40*, 463–474.

BORRERO, J. C., & VOLLMER, T. R. (2002). An application of the matching law to severe problem behavior. *Journal of Applied Behavior Analysis, 35*, 13–27.

CATANIA, A. C. (1963). Concurrent performances: A baseline for the study of reinforcement magnitude. *Journal of the Experimental Analysis of Behavior, 6,* 299–300.

CHUNG, S. H., & HERRNSTEIN, R. J. (1967). Choice and delay of reinforcement. *Journal of the Experimental Analysis of Behavior, 10,* 67–74.

CONGER, R., & KILLEEN, P. (1974). Use of concurrent operants in small group research: A demonstration. *Pacific Sociological Review, 17,* 399–416.

DAVISON, M., & BAUM, W. M. (2003). Every reinforcer counts: Reinforcer magnitude and local preference. *Journal of the Experimental Analysis of Behavior, 80*, 95–129.

DAVISON, M., & HOGSDEN, I. (1984). Concurrent variable-interval schedule performance: Fixed versus mixed reinforcer durations. *Journal of the Experimental Analysis of Behavior, 41,* 169–182.

DAVISON, M., & MCCARTHY, D. (1988). *The matching law: A research review.* Hillsdale, NJ: Erlbaum.

DOUGHTY, A. H., CIRINO, S., MAYFIELD, K. H., DA SILVA, S. P., OKOUCHI, H., & LATTAL, K. A. (2005). Effects of behavioral history on resistance to change. *The Psychological Record, 55,* 315–330.

HERRNSTEIN, R. J. (1961). Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior, 4,* 563–573.

HOCH, J., & SYMONS, F. J. (2007). Matching analysis of socially appropriate and destructive behavior in developmental disabilities. *Research in Developmental Disabilities, 28,* 238–248.

HOUSTON, A. (1986). The matching law applies to wagtails' foraging in the wild. *Journal of the Experimental Analysis of Behavior, 45*, 15–18.

IWATA, B. A. (1987). Negative reinforcement in applied behavior analysis: An emerging technology. *Journal of Applied Behavior Analysis, 20*, 361–378.

IWATA, B. A., DORSEY, M. F., SLIFER, K. J., BAUMAN, K. E., & RICHMAN, G. S. (1994). Toward a functional analysis of self-injury. *Journal of Applied Behavior Analysis, 27,* 197–209. (Reprinted from *Analysis and Intervention in Developmental Disabilities, 2*, 3–20, 1982)

IWATA, B. A., KAHNG, S., WALLACE, M. D., & LINDBERG, J. S. (2000). The functional analysis model of behavioral assessment. In J. Austin & J. E. Carr (Eds.), *Handbook of applied behavior analysis* (pp. 61–89). Reno, NV: Context Press.

IWATA, B. A., PACE, G. M., KALSHER, M. J., COWDERY, G. E., & CATALDO, M. F. (1990). Experimental analysis and extinction of self-injurious escape behavior. *Journal of Applied Behavior Analysis, 23*, 11–27.

MADDEN, G. J., PEDEN, B. F., & YAMAGUCHI, T. (2002). Human group choice: Discrete-trial and free-operant tests of the ideal free distribution. *Journal of the Experimental Analysis of Behavior, 78,* 1–15.

MCDOWELL, J. J (2005). On the classic and modern theories of matching. *Journal of the Experimental Analysis of Behavior, 84,* 111–127.

MILLER, H. L. JR. (1976). Matching-based hedonic scaling in the pigeon. *Journal of the Experimental Analysis of Behavior, 26*, 335–347.

MOORE, J. (2008). A critical appraisal of contemporary approaches in the quantitative analysis of behavior. *The Psychological Record, 58,* 641–664.

OKOUCHI, H. (2007). An exploration of remote history effects in humans. *The Psychological Record, 57,* 241–263.

OLIVER, C., HALL, S., & NIXON, J. (1999). A molecular to molar analysis of communicative and problem behavior. *Research in Developmental Disabilities, 20,* 197–213.

PIERCE, W. D., & EPLING, W. F. (1983). Choice, matching, and human behavior: A review of the literature. *The Behavior Analyst, 6,* 57–76.

ST. PETER, C. C., VOLLMER, T. R., BOURRET, J. C., BORRERO, C. S. W., SLOMAN, K. M., & RAPP, J. T. (2005). On the role of attention in naturally occurring matching relations. *Journal of Applied Behavior Analysis, 38,* 429–443.

SHULL, R. L. (1991). Mathematical descriptions of operant behavior: An introduction. In I. H. Iverson & K. A. Lattal (Eds.), *Experimental Analysis of Behavior, Part II: Techniques in the behavioral and neural sciences* (Vol. 6, pp. 243–282). New York: Elsevier Science.

SKINNER, B. F. (1935). The generic nature of the concepts of stimulus and response. *The Journal of General Psychology, 12,* 40–65.

SMITH, R. G., & CHURCHILL, R. M. (2002). Identification of environmental determinants of behavior disorders through functional analysis of precursor behaviors. *Journal of Applied Behavior Analysis, 35,* 125–136.

SYMONS, F. J., HOCH, J., DAHL, N. A., & MCCOMAS, J. J. (2003). Sequential and matching analyses of self-injurious behavior: A case of overmatching in the natural environment. *Journal of Applied Behavior Analysis, 36,* 267–270.

VOLLMER, T. R., & BOURRET, J. (2000). An application of the matching law to evaluate the allocation of two- and three-point shots by college basketball players. *Journal of Applied Behavior Analysis, 33,* 137–150.

VOLLMER, T. R., & SAMAHA, A. L. (2006). Some implications of complex contingencies for Applied Behavior Analysis. *European Journal of Behavior Analysis, 7,* 121–123.