CONCURRENT REINFORCEMENT SCHEDULES FOR PROBLEM BEHAVIOR AND APPROPRIATE BEHAVIOR: EXPERIMENTAL APPLICATIONS OF THE MATCHING LAW

By

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by

Carrie S. W. Borrero
To my grandmothers, Grace Geraci Lipari and Dorothy Walsh Wright.
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The purpose of this study was to determine if children who exhibit problem behavior would allocate responding in direct proportion to experimentally arranged reinforcement rates. Relative reinforcer rates were manipulated to evaluate changes in relative response rate on concurrent variable-interval (VI) schedules, and results were interpreted using two iterations of the matching equation: the strict (simple) matching equation (Herrnstein, 1961) and the generalized matching equation (Baum, 1974a).

Three individuals diagnosed with developmental disabilities, who engaged in severe problem behavior, participated. In Experiment 1, functional analyses were conducted to determine the reinforcers for problem behavior. Results showed that problem behavior was sensitive to social positive reinforcement in the form of access to tangible items and social negative reinforcement in the form of escape from instructional demands for one participant, social positive reinforcement in the form of access to tangible items for
another, and social positive reinforcement in the form of attention and social negative reinforcement in the form of escape from instructional demands for the third participant. In Experiment 2, concurrent schedules of reinforcement were in place for both problem and appropriate behavior. Results showed that the relative rates of responding approximated the relative rates of reinforcement. In addition, interventions for problem behavior were evaluated, and differential reinforcement of alternative behavior (DRA) and extinction (EXT) procedures were implemented to increase the rate of appropriate behavior and decrease the rate of problem behavior.
CHAPTER 1
INTRODUCTION

Choice has been defined as the emission of one of two or more alternative and usually incompatible responses (Catania, 1998). Typical laboratory arrangements implement concurrent-schedules with two or more alternatives, with each alternative correlated with a reinforcement schedule. Herrnstein (1961) provided a quantitative description of responding on concurrent schedules of reinforcement, known as the matching law. Generally, the matching law states that the relative rate of responding on one alternative will approximate the relative rate of reinforcement provided on that alternative. Baum (1974a) provided an alternative formulation of the matching law, known as the generalized matching law that accounted for deviations from strict matching by incorporating a bias parameter and a sensitivity parameter.

The matching law has been evaluated in a number of investigations using both non-humans (Baum; Baum, 1974b; Baum, 1979; Belke & Belliveau, 2001; Crowley & Donahoe, 2004; Herrnstein; Herrnstein & Loveland, 1975; MacDonall, 1988, McSweeney, Farmer, Dougan, & Whipple, 1986) and humans (e.g., Borrero & Vollmer, 2002; Mace, Neef, Shade, & Mauro, 1994; Martens & Houk, 1989; McDowell, 1981; Neef, Mace, Shea, & Shade, 1992; Oliver, Hall, & Nixon, 1999; Symons, Hoch, Dahl, & McComas, 2003; Vollmer & Bourret, 2000). Previous research with humans has included both experimental and descriptive analyses of responding however, the experimental evaluations of the matching law have evaluated academic responding (Mace
et al.; Neef & Lutz, 2001; Neef, Mace & Shade, 1993; Neef, Shade & Miller, 1994), while the descriptive studies (Borrero & Vollmer; Martens & Houk; McDowell; Oliver et al.; Symons et al.) have focused on severe problem behavior such as aggression, property destruction, and self-injurious behavior (SIB). The present study involved experimental analyses of responding on concurrent reinforcement schedules for individuals with developmental disabilities who engaged in severe problem behavior. Results were then evaluated using both the simple (Herrnstein) and generalized (Baum) matching equations.

**Definition and Historical Overview**

Herrnstein (1961) evaluated the effects of relative reinforcement frequency on relative response frequency using concurrent variable-interval (VI) schedules. Initially, training was conducted with 3 pigeons in order to establish key-pecking and alternation of responding between two keys. Following training, pigeons were exposed to a sequence of concurrent VI schedules for both keys: VI 3 min VI 3 min, VI 2.25 min VI 4.5 min, VI 1.8 min VI 9 min, and VI 1.5 min extinction (EXT). During most of the experiment, a change-over delay (COD) was implemented such that when pigeons switched keys, no reinforcer was possible for 1.5 s. Herrnstein plotted the percentage of responses across the percentage of reinforcements provided for that alternative and demonstrated that the relative response rate increased as the relative reinforcement rate increased in a linear relationship. In addition, Herrnstein found that the COD had three effects on responding: (a) when the COD was in effect, switching between the two keys decreased, and (b) only when the COD was in effect did unequal reinforcement schedules on the two keys reduce switching, and (c) when the COD was not present, as compared to when the COD was present, matching was not obtained for two pigeons.
Herrnstein (1961) described the relative rate of responding and the relative rate of reinforcement with the following Equation (1-1):

\[
\frac{R_1}{R_1 + R_2} = \frac{r_1}{r_1 + r_2}
\]

where, \(R_1\) refers to the rate of responding on one alternative, and \(R_2\) refers to the rate of responding for a second alternative, while \(r_1\) is the rate of reinforcement for one alternative (\(R_1\)) and \(r_2\) is the rate of reinforcement for the second alternative (\(R_2\)). Results suggested that relative response rate increased as a function of relative rate of reinforcement, although this result was only observed when the COD was in place.

Baum (1974b) presented a variation of the matching equation now known as the Generalized Matching Equation. The Generalized Matching Equation may be expressed as follows (Equation 1-2):

\[
\log \left( \frac{B_1}{B_2} \right) = a \log \left( \frac{R_1}{R_2} \right) + \log b
\]

where \(B_1\) and \(B_2\) refer to the frequency of responding on the alternatives, and \(R_1\) and \(R_2\) represent the relative rates of reinforcement from each alternative. The generalized matching equation takes into account bias (\(b\)) and the slope (\(a\)) of the function, which provides information regarding sensitivity. These additional parameters provide information useful in determining if undermatching or bias occur. Undermatching refers to less than a one-unit increase in log ratio of responding produced by a one-unit increase in log ratio of reinforcement. When undermatching occurs, the slope is less than 1.

Baum (1974b) suggested several factors that may lead to undermatching, including (a) poor discrimination (e.g., the organism does not discriminate between the two schedules), (b) absence of a COD, and (c) states of deprivation.
Bias refers to systematic deviations in responding that cannot be attributed to the relative reinforcement rates. When bias occurs, \( b \) differs from 1. If \( b \) is less than 1, this suggests that the organism favors the response in the denominator \( (B_2) \). If \( b \) is greater than 1, this suggests that the organism favors the response in the numerator \( (B_1) \). Baum (1974b) described factors that may lead to bias including (a) response bias (e.g., one response may be more effortful than the other, color preferences, etc.), (b) a discrepancy between scheduled and obtained reinforcement, (c) qualitatively different reinforcers (e.g., hugs vs. reprimands, hemp vs. grain), and (d) qualitatively different schedules (e.g., VI vs. fixed-ratio [FR]).

A number of applied studies have evaluated naturally occurring situations using the matching law. McDowell (1981) applied the single alternative formulation of the matching law (Herrnstein, 1970) to evaluate data originally reported by Carr and McDowell (1980). The single alternative formulation of the matching law may be expressed as follows (Equation 1-3):

\[
R = \frac{kr}{r + r_e}
\]

where \( R \) represents response rate, and \( r \) represents reinforcement rate for single-alternative environments. The parameter \( k \) is the \( y \)-asymptote and represents the total amount of behavior in which the organism can engage. Finally, \( r_e \) represents all other reinforcement not represented by \( r \), and describes how quickly the function reaches its asymptote. The larger the \( r_e \), the more slowly the asymptote is reached, and generally, a larger \( r_e \) value suggests a “richer” environment.

McDowell (1981) evaluated self-injurious scratching displayed by an 11 year-old boy. In the initial investigation by Carr and McDowell (1980), the rates of self-
scratching and verbal reprimands were recorded during naturalistic observations between the boy and his parents. Next, the researchers conducted an assessment and determined that verbal reprimands reinforced self-scratching. Finally, they implemented an intervention including a time-out component and a positive reinforcement component, which decreased self-scratching. McDowell evaluated the data from the naturalistic situation, and found that the boy’s naturally occurring rates of self-scratching conformed to Equation 3 as a function of adult attention. The single alternative formulation of the matching law accounted for 99.67% of the variance in the rate of scratching observed, and the results suggested Equation 3 provided a comprehensive description for human behavior occurring in a non-laboratory environment (i.e., the natural environment).

In a related study, Martens and Houk (1989) evaluated the single alternative formulation of the matching law to describe disruptive behavior and academic responding in a classroom setting, with an 18-year-old woman diagnosed with developmental disabilities and the staff in her classroom. They evaluated matching based on time allocation between disruptive behavior (e.g., vocal outbursts, skin picking, off-task behavior, etc.) and on-task behavior (e.g., independent work, compliance with requests, and instructional interactions). Attention delivered from the teacher or classroom aide was presumed to be a reinforcer by way of correlational analyses. Results showed that the matching equation was useful in describing response allocation between the two alternatives as a function of adult attention, and accounted for 83% of the variance observed in disruptive behavior.

Oliver et al. (1999) evaluated time allocation between problem behavior (i.e., aggression) and communicative behavior (e.g., sign language) with a 7-year-old boy
diagnosed with Down syndrome. First, the researchers conducted a descriptive analysis in the classroom across various activities. They then conducted an experimental analysis using procedures similar to those described by Carr and Durand (1985) to identify reinforcers for aggression. Based on the results from the descriptive and experimental analyses, Oliver et al. concluded that the boy’s aggression was reinforced by escape from instructional demands. Finally, the researchers applied variations of the simple (1) and generalized matching equations (2) in which time allocation (and not response rate) was evaluated as a function of duration (and not rate) of reinforcement (e.g., Baum & Rachlin, 1969).

There are two potential limitations to the investigations described above. First, Martens and Houk (1989) did not confirm that attention was in fact a reinforcer for problem behavior. Research on functional analysis methods (see Hanley, Iwata & McCord, 2003, for a recent review) demonstrates the utility of identifying events as reinforcers, and it is not necessary to assume an event is a reinforcer. Although Oliver et al. (1999) did conduct experimental manipulations in an effort to identify reinforcers using methods described by Carr and Durand (1985), they did not experimentally manipulate consequences for problem behavior. Second, functional analysis research has demonstrated that problem behavior may be multiply controlled by several sources of reinforcement, including access to tangible items and escape from instructional activities. The studies by McDowell (1981) and Martens and Houk did not take into account whether problem behavior was sensitive to additional sources of reinforcement.

To address these potential limitations, Borrero and Vollmer (2002) conducted an investigation to evaluate the matching law by identifying reinforcers for problem
behavior using the functional analysis method of behavioral assessment, and interpreting
descriptive analysis data using identified reinforcers. The researchers conducted
descriptive analyses in an inpatient hospital setting or classroom setting for 4 individuals
diagnosed with developmental disabilities. All participants engaged in severe problem
behavior (e.g., property destruction, aggression, and SIB) as well as appropriate behavior
(e.g., vocal requests, gestures, and compliance with instructional demands). Next,
Borrero and Vollmer conducted functional analyses using procedures similar to those
described by Iwata, Dorsey, Slifer, Bauman, and Richman (1982/1994) and identified
reinforcers for problem behavior for all participants. Finally, they evaluated the
descriptive data using both the simple and generalized matching equations (Equations 1
and 2). Results showed that the relative rate of problem behavior approximately matched
the relative rate of reinforcement for problem behavior for all participants. In addition,
they evaluated multiple sources of reinforcement based on the results from the functional
analysis and found that responding was better described by the matching equation when
several possible sources of reinforcement were included in the analysis.

Additional research on the matching law with individuals who engage in problem
behavior has also included analyses of behavior occurring during naturally occurring
interactions (e.g., St. Peter et al., 2005) however no experimental analysis of the
matching law has been conducted for such individuals. As noted previously, the majority
of descriptive research evaluating the matching law has involved evaluations of problem
behavior, while experimental research has largely focused on academic tasks (e.g., Mace
et al., 1994; Neef et al., 1993; Neef et al., 1992; Neef et al., 1994).
Neef et al. (1992) conducted an investigation to demonstrate that (a) human behavior is sensitive to concurrent schedules of reinforcement when reinforcer quality is held constant, as suggested by the matching law and (b) the matching relation would not occur when reinforcer quality was not equal, and that a bias for the higher quality reinforcer would occur. The participants were individuals diagnosed with emotional disturbances and learning difficulties. Prior to each session, the participant was asked if she preferred to work for nickels or tokens. During each session, identical stacks of arithmetic problems were placed in front of the participant, where each stack of cards was associated with a VI schedule of reinforcement (e.g., VI 30-s, VI 120-s), and correct responses resulted in reinforcement (e.g., nickels or tokens) delivered according to the schedule in place for that alternative.

Initially, sessions were conducted to identify the participants’ sensitivity to the VI schedules of reinforcement, and a timer was included to signal the amount of time remaining in the reinforcement interval. Neef et al. (1992) then evaluated two additional conditions: (a) equal-quality reinforcers, during which two stacks of cards were presented on concurrent VI schedules, and the reinforcers delivered were the same (i.e., either nickels or tokens were delivered for both alternatives), and (b) unequal-quality reinforcers, during which two stacks of cards were presented on concurrent VI schedules, and high-quality reinforcers were delivered on the leaner schedule of reinforcement (i.e., VI 120-s) and low-quality reinforcers were delivered on the richer schedule of reinforcement (i.e., VI 30-s). During the initial condition, responding was not allocated as would be predicted by the concurrent VI schedules until the timer was included to signal the reinforcement intervals. For all participants, time-allocation matching occurred
following the introduction of the timer. During the equal-quality reinforcers condition, matching was observed, with the time allocated to each response alternative closely approximating the obtained reinforcement from that alternative. During the unequal-quality reinforcers condition, matching was not observed, and responding suggested a preference for one of the two alternatives (i.e., nickels or tokens) for two participants, or responding that maximized the number of reinforcers for that alternative, for one participant. This study provided support for the applicability of the matching relation to socially significant human behavior, and highlighted some potentially important considerations, including the use of additional procedural manipulations (e.g., timer to signal reinforcement intervals) to improve discrimination between concurrent VI schedules, and biased responding, which may occur if the quality of available reinforcers is not equal.

Using the same general procedures described in prior work (i.e., Neef et al., 1992), Neef and colleagues (Mace et al., 1994; Neef et al., 1993; Neef et al., 1994) extended the work reported by Neef et al. (1992) and showed that response allocation under concurrent VI schedules was also sensitive to additional reinforcement parameters including reinforcer delay. Because this series of experiments involved academic behavior of individuals with emotional and learning disabilities the generality of the matching law was extended to socially significant (appropriate) behavior.

Collectively, previous research suggests a need for an experimental analysis of severe problem behavior exhibited by individuals with developmental disabilities, under concurrent reinforcement schedules, using the matching law (Baum, 1974a, Herrnstein, 1961) as a conceptual framework. Prior research has supported the matching law as a
description of behavior across a number of settings, including the nonhuman laboratory, natural environment, the human laboratory, and instructional situations. The purpose of this dissertation was to conduct experimental analyses of problem behavior with 3 individuals diagnosed with developmental disabilities who engaged in severe problem behavior. In Experiment 1, functional analyses were conducted for all participants to identify reinforcers for problem behavior. Specifically, conditions were included to determine if problem behavior was sensitive to (a) social positive reinforcement, including adult attention or access to preferred tangible items (e.g., toys, edible items, etc.), (b) social negative reinforcement, including escape from instructional demands or aversive situations (e.g., hygiene tasks, daily living skills, etc.), or (c) automatic reinforcement, suggesting that the reinforcer for problem behavior is not socially-mediated (e.g., sensory reinforcement, pain alleviation, etc.).

In Experiment 2, concurrent schedules of reinforcement were introduced for problem behavior and appropriate behavior (using reinforcers previously identified in Experiment 1). Appropriate behavior was identified during formal descriptive observations of each participant as well as during the functional analysis, and included requests for access to tangible items (e.g., using picture cards, sign language, or vocal requests), compliance with instructions, and gestures toward tangible items (e.g., reaching for items, pointing to objects, etc.). For each participant, concurrent schedules of reinforcement were arranged for problem behavior and appropriate behavior, with one schedule being richer than the other (i.e., more reinforcement was available for either problem or appropriate behavior), or the schedules being equal (2 participants). Following changes in responding with exposure to the schedule arrangement, the
schedules for problem and appropriate behavior were switched. That is, if the initial
phase included a VI 20-s schedule for problem behavior and a VI 60-s schedule for
appropriate behavior, the schedules were switched during the second phase such that a VI
60-s schedule was in place for problem behavior and a VI 20-s schedule was in place for
appropriate behavior. Additional replications for all phases were conducted. Finally, for
all participants, an intervention phase was included to decrease problem behavior,
including a continuous reinforcement schedule (CRF) for appropriate behavior, and
extinction (EXT) for all problem behavior. That is, during the intervention phase, all
instances of appropriate behavior resulted in access to the reinforcer, and all instances of
problem behavior did not result in access to the reinforcer. The goal of the intervention
phase was to reduce problem behavior to clinically significant levels and increase levels
of appropriate behavior.
CHAPTER 2
EXPERIMENT 1: FUNCTIONAL ANALYSIS OF PROBLEM BEHAVIOR

Method

Participants

Three individuals diagnosed with developmental disabilities who engaged in severe problem behavior participated. Greg was an 8-year-old boy diagnosed with mild mental retardation and autism. His problem behavior included screaming, defined as vocalizations at a volume louder than conversation level, and disruptive behavior, defined as throwing, hitting, or kicking objects. Audrey was a 14-year-old female diagnosed with mental retardation. Her problem behavior included SIB, defined as hitting her chin, nose and face with a closed fist, as well as self-choking (i.e., pushing her fingertips into her throat). Alice was a 13-year-old girl who was diagnosed with childhood disintegrative disorder. Her problem behavior included disruption, defined as throwing objects, and aggression, defined as hitting and kicking others.

Setting

For Greg and Alice, functional analyses were conducted on an inpatient hospital unit for the assessment and treatment of problem behavior at the University of Florida. All sessions were conducted in a room with a table and chairs. Audrey’s assessment was conducted at a local school, and sessions were conducted in an available classroom, furnished with desks and chairs.
**Procedure**

All sessions were conducted by trained graduate students serving as experimenters. Observers were graduate and undergraduate students who received in-vivo training in behavioral observation and had previously demonstrated high interobserver agreement (IOA) scores (> 90%) with trained observers. Observers in the hospital setting were seated behind a one-way mirror or sat unobtrusively at a table in the room. In the classroom setting, observers were seated unobtrusively at a desk in the classroom. Observers collected data on personal digital assistants (PDA) that provided real-time data and scored events as either frequency (e.g., aggression, disruption, SIB, and screaming), or duration (e.g., delivery of attention, escape from instructions, etc.). Sessions were conducted two to three times each day, four days per week, and were 10 min in duration (with the exception of one control session for Audrey).

**Stimulus Preference Assessment.** Prior to the functional analyses, free-operant stimulus preference assessments were conducted using procedures described by Roane, Vollmer, Ringdahl, and Marcus (1998) to identify preferred items to be included in the conditions of the functional analysis, for each participant. An array of 6-8 leisure items (e.g., musical keyboard, drawing toys, music, etc.) was placed on the floor or a table. Before beginning the assessment, the participant was shown the item and allowed brief (i.e., 2-3 s) contact with the item. The participant was then told that he or she could play with any of the items, and the duration of time the participant interacted with each item was scored. Preferred items were considered to be the three items for which interaction was of the greatest duration.

**Functional analysis.** Functional analyses were conducted using procedures similar to those described by Iwata et al. (1982/1994). Four test conditions were
compared: (a) attention, (b) tangible, (c) escape, and (d) no consequence (Audrey and Alice only), to a control condition (play) using a multielement design for all participants. Consequences for problem behavior were provided contingent on screaming or disruption (Greg), SIB (Audrey), and aggression or disruption (Alice).

During the attention condition, the participant was provided with preferred tangible items, and no demands were presented, while the therapist diverted her attention to a work task. Contingent on problem behavior, brief attention was provided for 30 s and consisted of a reprimand (e.g., “Don’t do that”) followed by the therapist conversing with the participant. This condition was included to determine if problem behavior was reinforced by adult attention. During the tangible condition, the participant was provided with adult attention and no demands were present, while the therapist restricted access to preferred tangible items. Contingent on problem behavior, access to preferred items was provided for 30 s. This condition was included to determine if problem behavior was reinforced by access to tangible items. During the escape condition, the therapist provided instructional demands (e.g., brushing teeth, washing face, combing hair, folding towels) using a three-prompt instructional sequence (Horner & Keilitz, 1975). Contingent on problem behavior, a 30-s break from instructions was provided and the task materials were removed. This condition was included to determine if problem behavior was negatively reinforced by escape from instructional demands. During the no consequence condition (Audrey and Alice only) all preferred tangible items were removed, and the participant received no attention from the therapist. There were no programmed consequences for problem behavior. This condition was included to determine if problem behavior persisted in the absence of programmed social
consequences. Finally, during the control condition, the participant had continuous access to preferred tangible items, no demands were present, and adult attention was provided at least every 30 s. There were no programmed consequences for problem behavior. This condition was included as a point of comparison to the test conditions.

**Interobserver agreement (IOA).** Two independent observers collected data on aggression, disruption, screaming, and SIB for a proportion of functional analyses sessions to assess interobserver agreement (IOA). In addition, observers collected data on the delivery of attention, access to tangible items, and escape from instructional demands, and IOA was assessed. Observations were divided into 10-s bins, and the number of observed responses was scored for each bin. The smaller number of observed responses within each bin was divided by the larger number of observed responses and converted to agreement percentages for frequency measures (Iwata, Pace, Kalsher, Cowdery, & Cataldo, 1990). Agreement on the nonoccurrence of behavior within any given bin was scored as 100% agreement. The bins were then averaged across the session. In a session, the smaller number of s was divided by the larger number of s for duration measures (and agreement on the nonoccurrence of behavior within any bin was scored as 100% agreement). The bin data were then averaged across the sessions. For Greg, IOA was scored for 53% of functional analysis sessions, and averaged 98.7% for disruption (range, 96% to 100%), and 94.4% for screaming (range, 84% to 100%). IOA averaged 100% for therapist attention, and 97% for access to tangible items (range, 91.1% to 100%), and 99.8% for escape from instructions (range, 99.4% to 100%).

For Audrey, IOA was scored for 28% of functional analysis sessions, and averaged 94% for SIB (range, 76% to 100%). IOA averaged 88% for therapist attention (range,
11% to 100%), 98% for access to tangible items (range, 92% to 100%), and 97% for escape from instructions (range, 86% to 100%).

For Alice, IOA was scored for 42% of functional analysis sessions, and averaged 98.5% for aggression (range, 93% to 100%) and 98% for disruption (range, 95% to 100%). IOA averaged 82.75% for therapist attention (range, 26% to 100%), 87% for access to tangible items (range, 1% to 100%), and 94% for escape from instructions (range, 80% to 100%).

**Results and Discussion**

Figure 2-1 shows the results of the functional analyses for Greg and Alice. Panel A of Figure 2-1 shows responses per min (rpm) of screaming for Greg. The highest rates of screaming occurred in the tangible condition, with a mean response rate of 1.68 rpm, as compared to the attention ($M = .05$ rpm), escape ($M = .34$ rpm), and control ($M = 0$ rpm) conditions. These results suggested that Greg’s screaming was reinforced by access to tangible items. In addition, for Greg, Panel B of Figure 2-1 shows the responses per min of disruption. The highest rates of disruption were observed during the escape condition, with a mean response rate of .4 rpm, as compared to the attention, tangible, and control conditions, which all had 0 rpm of disruption. Although the rate was low even in the escape condition, the behavior was correlated with demand presentation and never occurred in conditions other than escape. These results suggested that Greg’s disruption was reinforced by escape from instructional demands. In Greg’s case, screaming and disruption served different operant functions.

Panel C of Figure 2-1 shows the results of Alice’s functional analysis. The highest rates of aggression and disruption were observed during the escape ($M = .7$ rpm) and attention ($M = .6$ rpm) conditions, when compared to the no consequence ($M = 0$ rpm),
tangible \((M = .05 \text{ rpm})\), and control \((M = .05 \text{ rpm})\) conditions. These results suggested that Alice’s aggression and disruption were reinforced by adult attention, and escape from instructional demands. Data were collected for aggression and disruption separately and similar results were obtained, therefore both topographies were combined in this analysis. That is, there was no evidence to suggest that aggression or disruption served distinct functions.

For Audrey, SIB rates seemed to carry over from one session to the next. As a result, overall session mean rates looked similar across conditions even though the therapists reported what seemed to be obviously different effects of the functional analysis conditions. Because extinction bursts and carryover effects may have influenced overall session mean rates, a within-session (min-by-min) analysis was used to identify the operant functions of her SIB (Vollmer, Iwata, Zarcone, Smith, & Mazaleski, 1993).

Figure 2-2 shows the within-session results from Audrey’s functional analysis. The very first session was a no consequence session. However, prior to the session a therapist removed access to tangible items. She engaged in a burst of SIB and reaching for the items that persisted through the first session. A similar burst was seen in the second no consequence session (seventh overall session); however, by the end of the session SIB had extinguished. A third no consequence session conducted immediately thereafter produced very low rates. Thus, although high mean rates of SIB were observed in two no consequence sessions, the within-session data suggest that the behavior was not automatically reinforced. In all three tangible sessions, SIB occurred at very stable rates and occurred almost immediately upon removal of the tangible items. The SIB would characteristically stop when the tangible items were returned to her. This effect resulted
in a SIB rate of approximately 2.0 per min (the same rate at which the establishing operation was put in place). Rates of SIB were high in the escape condition and were highly correlated with demands. By the second escape session (twelfth overall session), she had become more “efficient” and engaged in minimal SIB, primarily when demands were presented. Rates of SIB were zero in attention sessions (possibly a false negative if the reinforcing effects of attention were outweighed by continuous access to tangibles, but this possibility was not evaluated). Occasional bursts occurred at the beginning of control sessions but the rate almost always waned by the end of the session. Overall the functional analysis data suggested that Audrey’s SIB was reinforced by escape and access to tangibles. It is possible that SIB would have been influenced by attention if preferred tangibles were not included in her sessions, but for the purposes of this study it was important to identify at least one source of reinforcement for SIB and a more detailed evaluation of attention was not pursued.

In summary, results of Experiment 1 identified the socially-mediated reinforcers for the problem behavior exhibited by three individuals diagnosed with developmental disabilities. For all participants, problem behavior was multiply controlled; that is, problem behavior was reinforced by more than one type of event. Two individuals engaged in problem behavior reinforced by access to tangibles, one engaged in problem behavior reinforced by adult attention, and all three engaged in problem behavior reinforced by escape from instructional demands. This experiment was a necessary prerequisite to Experiment 2.

The results of Experiment 1 provided a basis for Experiment 2, during which concurrent reinforcement schedules were in place for both problem and appropriate
behavior. Such analyses would not have been possible without identifying the
function(s) of problem behavior. In Experiment 2, we attempted to evaluate how
responding would be allocated between concurrent schedules of reinforcement. In
addition, for all participants, we eventually conducted interventions to reduce problem
behavior to low levels and increase appropriate behavior.
Figure 2-1. Overall response rates for Greg and Alice during the functional analysis phase. A) Responses per min of screaming for Greg. B) Responses per min of disruption for Greg. C) Responses per min of disruption and aggression for Alice.
Figure 2-2. Within session response rates for Audrey during the functional analysis phase. A) Responses per minute of self-injurious behavior for Audrey.
CHAPTER 3
EXPERIMENT 2: ANALYSIS OF CONCURRENT SCHEDULES OF REINFORCEMENT AND TREATMENT OF PROBLEM BEHAVIOR

Method

Participants

Participants were the same three individuals who participated in Experiment 1. Problem behavior was defined for each participant as in Experiment 1, and appropriate behavior was also assessed for each participant. Greg’s appropriate behavior was defined as vocal requests for preferred tangible items (e.g., “Toys”), and compliance with instructional demands (e.g., hygiene tasks). Audrey’s appropriate behavior was defined as requests for preferred tangible items (e.g., reaching for item). Alice’s appropriate behavior was defined as requests for a break from instructional demands through the use of a microswitch. When Alice touched the microswitch, a recorded message (e.g., “Break, please”) played. Due to clinical exigencies, Audrey’s escape behavior and Alice’s attention maintained behavior were addressed outside the context of this research.

Setting

The setting was the same as in Experiment 1. For two participants (Greg and Alice), analyses were conducted on an inpatient hospital unit for the assessment and treatment of problem behavior. For one participant (Audrey), the analysis was conducted at a local school, in an available classroom, furnished with desks and chairs.
**Procedure**

Trained graduate students served as experimenters for all sessions. Observers were graduate and undergraduate students who received in-vivo training in behavioral observation and who had previously demonstrated high interobserver agreement scores (> 90%) with trained observers. Observers in the hospital setting were seated behind a one-way mirror or sat unobtrusively at a table in the room. In the classroom setting, observers were seated unobtrusively at a desk in the classroom. Observers collected data on PDA that provided real-time data and scored events as either frequency (e.g., aggression, disruption, SIB, and screaming), or duration (e.g., delivery of attention, escape from instructions). Sessions were conducted two to three times each day, four days per week, and lasted 10 min. All participants were exposed to an initial baseline condition, which was selected based on the results of Experiment 1. Each participant was exposed to four conditions using a reversal design in order to assess response allocation for both problem behavior and appropriate behavior on concurrent schedules of reinforcement. The order of the conditions varied slightly for each participant, and was assigned randomly.

**Baseline.** The baseline condition was identical to the condition(s) associated with problem behavior during the functional analysis. These conditions varied for each participant, and included the tangible condition for Greg, the tangible condition for Audrey, and the escape condition for Alice. During baseline, each instance of problem behavior resulted in delivery of the reinforcer (i.e., access to tangible items for Greg and Audrey, or escape from instructions for Alice). No programmed consequences were in place for appropriate behavior; that is, instances of appropriate behavior did not result in access to the reinforcer.
Matching Analysis. Concurrent schedules of reinforcement were in place for both problem and appropriate behavior (e.g., VI 10-s VI 10-s, VI 20-s VI 60-s) during the analysis. The intervals were timed using a computer program that signaled (to observers) when each schedule had elapsed. When reinforcement was available for a response (i.e., the interval elapsed) an observer signaled the therapist by holding up a colored card to signal available reinforcement for a given response (e.g., blue card for problem behavior, yellow card for appropriate behavior). An attempt was made to always keep the card display outside of the participants’ line of vision. The first instance of behavior following availability of a reinforcer resulted in delivery of the preferred tangible item for 30 s. After 30 s of reinforcer access, the item was removed and the timer was reset for that response. Participants were exposed to a subset of conditions, including either the problem behavior (rich) or equal concurrent schedules, and appropriate behavior (rich).

**Problem behavior (rich).** The analysis conditions included concurrent VI schedules for both responses: problem behavior and appropriate behavior. The *problem behavior (rich)* condition (Greg only) was concurrent VI schedules (i.e., VI 20-s VI 60-s), in which, the higher rate of reinforcement (i.e., VI 20-s schedule) was associated with problem behavior while the lower rate of reinforcement (i.e., VI 60-s schedule) was associated with appropriate behavior.

**Equal concurrent schedules.** The *equal concurrent schedules* condition (Audrey and Alice only) included concurrent VI schedules (i.e., VI 10-s VI 10-s, and VI 20-s VI 20-s) during which the schedules were equal for problem and appropriate behavior.

**Appropriate behavior (rich).** The *appropriate behavior (rich)* condition (all participants) included concurrent VI schedules (e.g., VI 30-s VI 10-s, VI 60-s VI 20-s,
and VI 60-s VI 10-s), in which the higher reinforcement rate was associated with appropriate behavior while the lower reinforcement rate was associated with problem behavior.

**Full treatment.** Finally, the treatment condition was designed to eliminate problem behavior, and during this condition, differential reinforcement of alternative behavior (DRA) was implemented. During DRA, problem behavior was placed on extinction (i.e., no reinforcers were delivered following problem behavior) and initially, each instance of appropriate behavior resulted in reinforcement (i.e., CRF schedule).

**Design.** For Greg, the baseline condition, both the problem behavior (rich) and the appropriate behavior (rich) conditions, and full treatment were conducted for the tangible and escape functions of problem behavior. These conditions were evaluated in an ABCBCDAD reversal design for the tangible condition, and a BCBCDAD reversal design for the escape function, in which A represents the baseline condition, B represents the problem behavior (rich) condition, C represents the appropriate behavior (rich) condition, and D represents the full treatment condition. For Audrey, the baseline condition (A), the equal concurrent schedules condition (E) appropriate behavior (rich) condition (C), and full treatment (D) were conducted for the tangible function in a reversal (i.e., ADADECEC) design. The problem behavior (rich) condition (B) was not conducted for Audrey due to the severity of her SIB. For Alice, the baseline condition (A), the equal concurrent schedules condition (E), appropriate behavior (rich) (C) condition, and full treatment (D) were conducted for the escape function in a reversal (i.e., AECECD) design. The problem behavior (rich) condition (B) was not conducted for Alice, because she was unexpectedly discharged from the hospital.
Data Analysis. For all participants, results were evaluated from a matching perspective. In order to do so, rates of reinforcement for both problem and appropriate behavior were calculated and applied to Equation 1 and Equation 2 to determine if the relative rates of responding for problem and appropriate behavior approximated the relative rates of reinforcement. Given the complexities of response-stimulus relations, it is not clear what the definition of a reinforced response is, so in order to address this potential concern, three definitions of a reinforced response were included, and were evaluated using Equations 1 and 2.

Last Response Method. One definition of a reinforced response was a response that occurred immediately prior to the delivery of a reinforcer. If problem behavior and appropriate behavior are temporally contiguous, and a reinforcer was delivered following one of the responses, it is possible that only the response that occurred immediately before the reinforcer delivery was “reinforced” (from the organism’s perspective). For example, if problem behavior occurred 5 s before a reinforcer was delivered, and appropriate behavior occurred 1 s before a reinforcer was delivered, using this method, only appropriate behavior would be considered to be a reinforced response. This method of calculation will be called the Last Response Method.

Within 10 s Method. A second definition of a reinforced response was a response that occurred 10 s before a reinforcer was delivered. If problem and appropriate behavior are temporally contiguous, and a reinforcer was delivered immediately following one of the responses, it is possible that both responses were reinforced (from the organism’s perspective). For example, if problem behavior occurred 5 s before a reinforcer was delivered, and appropriate behavior occurred immediately before a reinforcer was
delivered, using this method, both responses would be defined as reinforced. Although 10 s is somewhat arbitrary, some time value had to be adopted. This method of calculation will be called the *Within 10 s Method*.

**Programmed Reinforcer Method.** Finally, a third definition of a reinforced response was a response for which a reinforcer was delivered according to the programmed reinforcement schedule. In other words, whichever response actually produced the reinforcer was counted as the reinforced response. This method will be called the *Programmed Reinforcer Method*.

For all calculations, the rate of responding and reinforcement were calculated for both problem and appropriate behavior for each participant. The rate of responding was calculated by taking the number of responses during a session and dividing by the duration of the session, in min. The rate of reinforcement was calculated by taking the number of reinforced responses (according to each of the three definitions provided above) and dividing by the duration of the session, in min. The values obtained were then inserted into Equation 1 and Equation 2 to determine if the relative rates of responding approximated the relative rates of reinforcement for that response.

**Interobserver agreement (IOA).** IOA was calculated as in Experiment 1, and two independent observers collected data on aggression, disruption, screaming, and SIB, as well as appropriate responses including the use of picture cards, reaching, compliance with instructional demands, and requests for a tangible item. Sessions were divided into 10-s bins, and the number of observed responses was scored for each bin. The smaller number of observed responses within each bin was divided by the larger number of observed responses and converted to agreement percentages for frequency measures.
(Iwata et al., 1990). Agreement on the nonoccurrence of behavior within any given bin was scored as 100% agreement. The bins were then averaged across the session. In a session, the smaller number of s was divided by the larger number of s for duration measures (and agreement on the nonoccurrence of behavior within any given bin was scored as 100%). The bin scores were then averaged across the sessions. For Greg, IOA was scored for 47% of assessment sessions during the tangible condition, and averaged 100% for disruption, 95% for screaming (range, 80 to 100%), 94.4% for appropriate requests (range, 80.8 to 100%), and 91.7% for access to tangible items (range, 84.1 to 100%). IOA was scored for 44% of assessment sessions during the escape condition, and averaged 89.6% for disruption (range, 87.5-100%), 94.3% for compliance with instructional demands (range, 85.8 to 100%), and 88.7% for escape from instructions (range, 84.7 to 100%).

For Audrey, IOA was scored for 36% of assessment sessions, and averaged 95.2% for SIB (range, 80 to 100%), and 95% for reaching for tangible items (range, 80 to 100%), and 83% for access to tangible items (range, 15% to 97%).

For Alice, IOA was scored for 32% of assessment sessions, and averaged 98.5% for aggression (range, 94 to 100%), 93.17% for disruption (range, 82 to 100%), and 100% for a request for a break from instructional demands (range, 100 to 100%). IOA averaged 88% for escape from instructions (range 64 to 96%).

**Results and Discussion**

Panel A (top panel) of Figure 3-1 shows the results of the analysis for Greg, during the tangible condition. Responses per min of problem and appropriate behavior are displayed for all phases. The initial baseline (A) for the tangible condition (top panel) shows the sessions conducted during the functional analysis. Following the baseline,
Greg’s behavior was exposed to the problem behavior (rich) condition (B). During this condition Greg engaged in higher rates of problem behavior ($M = 2.21 \text{ rpm}$) than appropriate behavior ($M = .95 \text{ rpm}$). The schedules of reinforcement were then switched to VI 60-s for problem behavior and VI 20-s for appropriate behavior (i.e., appropriate behavior (rich) [C]). During this condition, similar rates of problem behavior ($M = 2.10 \text{ rpm}$) and appropriate behavior ($M = 2.1 \text{ rpm}$) were observed. During the reversal to the problem behavior (rich) condition (i.e., VI 20-s schedule for problem behavior and VI 60-s for appropriate behavior) higher rates of problem behavior ($M = 1.50 \text{ rpm}$) than appropriate behavior ($M = 1.10 \text{ rpm}$) were observed. During this condition, it was observed that Greg’s screaming occurred contiguous with appropriate requests for tangible items, and a 2-s COD was included. During the second appropriate behavior (rich) condition (i.e., VI 60-s VI 20-s) problem behavior occurred at a lower rate ($M = 3.30 \text{ rpm}$) relative to appropriate behavior ($M = 4.40 \text{ rpm}$). In order to produce a clinically acceptable treatment effect, problem behavior was placed on EXT and appropriate behavior was reinforced on a continuous reinforcement schedule (CRF) schedule (D) initially. In addition, because problem and appropriate behavior continued to occur together, the COD was increased to 5 s. Problem behavior decreased ($M = 2.79 \text{ rpm}$) and appropriate behavior continued to occur ($M = 3.30 \text{ rpm}$). For the final three sessions, the mean rate of problem behavior was .03 rpm. During a brief reversal to baseline levels of problem behavior increased ($M = 1.75 \text{ rpm}$), while appropriate behavior decreased relative to the previous condition ($M = .55 \text{ rpm}$). A final treatment phase was conducted and problem behavior decreased to low levels ($M = .82 \text{ rpm}$, 0 in the final two
sessions) and appropriate behavior returned to levels observed in previous phases ($M = 2.02$ rpm).

Panel B (lower panel) of Figure 3-1 displays the results of the analysis for Greg during the escape condition. The problem behavior (rich) condition (B) was implemented first, and during this phase, problem behavior occurred at a higher rate ($M = 2.50$ rpm) compared to appropriate behavior ($M = 1.1$ rpm). The appropriate behavior (rich) condition (C) was conducted next, and, during this condition, problem behavior occurred at a lower rate ($M = 1.10$ rpm) relative to appropriate behavior ($M = 2.10$ rpm). During a reversal to the problem behavior (rich) condition problem behavior occurred at a slightly higher rate ($M = 1.50$ rpm) relative to appropriate behavior ($M = 1.12$ rpm), with clear separation in response rates across the last five sessions of the condition. The appropriate behavior (rich) condition was replicated, and initially higher rates of problem behavior ($M = 2.34$ rpm) occurred relative to appropriate behavior ($M = .87$ rpm). Problem behavior appeared to be decreasing, and at that time, Greg left the hospital for approximately two weeks (depicted on Figure 3-1 by the dashed vertical line). Following his return to the inpatient unit, the appropriate behavior (rich) condition continued, and eventually problem behavior decreased across the condition ($M = 2.87$ rpm), while appropriate behavior continued to occur at stable levels ($M = .94$ rpm). In order to reduce problem behavior to clinically significant levels, a treatment condition (D) was conducted, and problem behavior was placed on extinction while appropriate behavior was reinforced on a CRF schedule. Problem behavior decreased to near zero levels ($M = .05$ rpm) and appropriate behavior occurred at stable levels ($M = .39$ rpm). During a brief reversal to the baseline condition problem behavior increased ($M = 1.70$ rpm) as
well as appropriate behavior ($M = 2.40$ rpm), and a final treatment condition resulted in a
decrease in problem behavior ($M = .12$ rpm) and stable levels of appropriate behavior ($M$
$= .86$ rpm).

Panel A of Figure 3-2 shows the results of the analysis for Audrey. Responses per
min of problem and appropriate behavior are displayed for all phases. During the initial
baseline (A) for Audrey, which included functional analysis sessions (sessions 1-3) and
additional baseline sessions (sessions 4-14), relatively high rates of SIB were observed
($M = 1.99$ rpm) and relatively low levels of appropriate behavior (i.e., reaching) were
observed ($M = .13$ rpm). In order to decrease SIB to low levels, a treatment phase (D)
was conducted, during which problem behavior was placed on EXT, and appropriate
behavior resulted in access to the reinforcer (i.e., tangible items) on a CRF schedule. SIB
decreased ($M = .86$ rpm) and appropriate behavior increased ($M = 1.44$ rpm) during this
phase. This effect was replicated during brief reversals to the baseline and treatment
conditions. During the reversal to the baseline condition, SIB increased ($M = 1.70$ rpm)
and appropriate behavior decreased slightly ($M = 1.17$ rpm). During the replication of the
treatment condition, SIB decreased ($M = .30$ rpm) and appropriate behavior increased ($M$
$= 1.50$ rpm). During the next phase, equal concurrent schedules (i.e., VI 10-s VI 10-s)
(E) were implemented for both problem behavior and appropriate behavior. The equal
concurrent schedules condition yielded similar rates of problem behavior ($M = 1.17$ rpm)
and appropriate behavior ($M = 1.24$ rpm). Following the equal concurrent schedules
condition, the appropriate behavior (rich) condition (C) was implemented. During this
condition, rates of problem behavior ($M = .97$ rpm) and appropriate behavior ($M = 1.60$
rpm) were similar, although towards the end of the phase, less problem behavior occurred
relative to appropriate behavior. Next, concurrent schedules were arranged for problem
behavior and appropriate behavior in which the absolute values for both schedules were
altered (VI 60-s VI 20-s), while continuing to favor appropriate behavior, and retaining
the same proportional difference (1:3) in place in the prior appropriate behavior rich
condition. Similar results were observed as in the previous appropriate behavior (rich)
condition, and problem behavior occurred at a slightly lower rate ($M = 0.23$ rpm) relative
to appropriate behavior ($M = 2.20$ rpm). The equal concurrent schedules condition was
then replicated and the rates of problem behavior ($M = 1.25$ rpm) and appropriate
behavior ($M = 1.31$ rpm) were similar. A replication of the appropriate behavior (rich)
condition was conducted, and initially, similar rates of problem behavior ($M = 1.60$ rpm)
and appropriate behavior ($M = 1.86$ rpm) occurred at similar rates, although towards the
end of the phase, problem behavior occurred at a lower rate than appropriate behavior.
Due to the severity of Audrey’s SIB, we implemented full treatment immediately
following baseline. We continued to implement the full treatment procedures for Audrey
outside the context of this research.

Panel B of Figure 3-2 shows the results of the escape analysis for Alice. The initial
baseline condition (A) shows the results from the functional analysis. The baseline
yielded high rates of problem behavior and no appropriate behavior (compliance).
During the equal concurrent schedules condition (E) problem behavior occurred at a
lower rate ($M = 0.39$ rpm) relative to appropriate behavior ($M = 0.90$ rpm). Next, the
appropriate behavior (rich) condition (VI 60-s VI 10-s) (C) was implemented, and during
this condition, problem behavior occurred at an inexplicably higher rate ($M = 2.20$ rpm)
relative to appropriate behavior ($M = 0.90$ rpm). Next, a replication of the equal
concurrent schedules condition was implemented, and problem behavior occurred at a higher rate ($M = 1.05$ rpm) relative to appropriate behavior ($M = .35$ rpm). During the replication of the appropriate behavior (rich) condition, more problem behavior ($M = 1.20$ rpm) occurred relative to appropriate behavior ($M = .27$ rpm). Finally, a treatment phase (D) was conducted during which problem behavior was placed on extinction and appropriate behavior was reinforced on a CRF schedule. During this phase, problem behavior ($M = .60$ rpm) occurred at relatively low rates (.20 rpm in final session), and appropriate behavior ($M = 2.94$ rpm) occurred at relatively high rates. Alice’s assessment was brief and additional replications were not conducted, due to her brief stay in the hospital.

Figures 3-3 through 3-10 show the results from the matching analysis (i.e., simple matching and generalized matching) for all participants. For all scatter plots showing the results using the simple matching equation (i.e., Figures 3-3, 3-5, 3-7, and 3-9), the scatter plots show proportional response rates as a function of proportional reinforcer rates. The dashed diagonal line represents perfect matching as described by Equation 1. Panel A (top left) shows the results using the last response method of calculation and Panel B (top right) shows the means for each condition using the last response method of calculation depicted in panel A. In Panel A, each data point represents a session, and in Panel B, each data point represents the mean for the last five sessions in each condition of the assessment. Panel C (middle left) shows the results using the within 10-s method of calculation and Panel D (middle right) shows the means for each condition using the within 10-s method of calculation. In Panel C, each data point represents a session, and in Panel D, each data point represents the mean for the last five sessions in each condition.
Finally, Panel E (bottom left) shows the results using the programmed reinforcer method of calculation and Panel F (bottom right) shows the means for each condition using the programmed reinforcer method of calculation. In Panel E, each data point represents a session, and in panel F, each data point represents the mean for the last five sessions in each condition.

For the results using the generalized matching equation (i.e., Figures 3-4, 3-6, 3-8, and 3-10), the scatter plots show the log response ratios plotted as a function of log reinforcer ratios. The linear equation depicts slope and bias. The dashed diagonal line represents perfect matching. The solid line is a best fit line. Panel A (top left) shows the results using the last response method of calculation and Panel B (top right) shows the means for each condition using the last response method of calculation. In Panel A, each data point represents a session, and in Panel B, each data point represents the mean for the last five sessions in each condition. Panel C (middle left) shows the results using the within 10-s method of calculation and Panel D (middle right) shows the means for each condition using the within 10-s method of calculation. In Panel C, each data point represents a session, and in Panel D, each data point represents the mean for the last five sessions in each condition. Finally, Panel E (bottom left) shows the results using the programmed reinforcer method of calculation and Panel F (bottom right) shows the means for each condition using the programmed reinforcer method of calculation. Again, in Panel E, each data point represents a session, and in Panel F, each data point represents the mean for the last five sessions in each condition.

Figure 3-3 shows the results from the matching analysis of the tangible condition using Equation 1-1 for Greg. Due to a computer virus that erased data on reinforcer
presentations, calculations could not be conducted for each session of each condition of Greg’s analyses. However, a reasonably representative number of sessions were available. Generally, for the last response method of calculation (Panel A), the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior (r = .80). During a number of sessions, more problem behavior was observed than would be predicted based on the rate of reinforcement for problem behavior. The means for each condition using the last response method of calculation (Panel B) also show that the relative rate of responding was correlated with the relative rate of reinforcement (r = .98). During the conditions with a higher rate of reinforcement for appropriate behavior (VI 60-s VI 20-s) slightly more problem behavior was observed than would be predicted based on the proportional rate of reinforcement for problem behavior (denoted by data points above the dashed diagonal line). For the within 10-s method of data calculation (Panel C, the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior (r = .80). During a number of sessions, less problem behavior was observed than would be predicted based on the proportional rate of reinforcement for problem behavior. The means for each condition using the within 10-s method of calculation (Panel D) also show that the relative rate of responding was correlated with the relative rate of reinforcement (r = .98). For the programmed reinforcer method of calculation (Panel E), the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior (r = .59), although during a number of sessions, less problem behavior was observed than would be predicted based on the proportional rate of reinforcement for problem behavior. The means for each
condition using the programmed reinforcer method of calculation (Panel F) also show that the relative rate of responding was correlated with the relative rate of reinforcement ($r = .99$). During the condition with a higher rate of reinforcement for problem behavior (VI 20-s VI 60-s) slightly less problem behavior was observed than would be predicted based on the proportional rate of reinforcement for problem behavior.

Figure 3-4 shows the results from Equation 1-2 for Greg during the tangible condition. Generally, for the last response method of calculation (Panel A), the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior, however the best fit line does not indicate close adherence to the matching equation ($r^2 = .45$). The means for each condition using the last response method of calculation (Panel B) also show that the relative rate of responding was correlated with the relative rate of reinforcement, and the best fit line indicated adherence to the matching equation ($r^2 = .92$). The slope for both panels was less than 1.0, which suggests that undermatching occurred. Undermatching refers to the occurrence of less behavior than would be predicted based on the relative rates of reinforcement. For the within 10-s method of calculation (Panel C), the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior, however the best fit line does not indicate close adherence to the matching equation ($r^2 = .28$) due to three sessions in particular during the second problem behavior rich condition. The means for each condition using the within 10-s method of calculation (Panel D) also show that the relative rate of responding was correlated with the relative rate of reinforcement, and the best fit line did not indicate strict adherence to the matching equation ($r^2 = .40$). The slope for both panels was less than 1.0, which
suggests that undermatching occurred. For the programmed reinforcer method of calculation (Panel E), the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior, and the best fit line approximated perfect matching ($r^2 = .60$). The means for each condition using the programmed reinforcer method of calculation (Panel F) also show that the relative rate of responding was correlated with the relative rate of reinforcement, and the best fit line indicated matching ($r^2 = .81$). The slope for both panels was less than 1.0, which suggests that undermatching occurred.

Figure 3-5 shows the results from the matching analysis of the escape condition using Equation 1-1 for Greg. Due to a computer virus, calculations could not be conducted for each session of each condition. Generally, for the last response method of calculation (Panel A), the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior ($r = .49$), however for a number of sessions, more problem behavior was observed than would be predicted based on the proportional rate of reinforcement for that response. For the most part, these sessions (with more problem behavior observed than would be predicted) were those during which more reinforcement was available for appropriate behavior relative to problem behavior (VI 60-s VI 20-s). The means for each condition using the last response method of calculation (Panel B) also show that the relative rate of responding was correlated with the relative rate of reinforcement ($r = .97$). During the conditions with a higher rate of reinforcement for appropriate behavior (VI 60-s VI 20-s) slightly more problem behavior was observed than would be predicted based on the proportional rate of reinforcement for problem behavior. For the within 10-s method of calculation (Panel C), the proportional
rates of problem behavior were positively correlated with the proportional reinforcement 
rates for problem behavior (r = .92). The means for each condition using the within 10-s 
method of calculation (Panel D) also show that the relative rate of responding was 
correlated with the relative rate of reinforcement (r = .78), however, more problem 
behavior was observed than would be predicted based on the proportional rate of 
reinforcement for problem behavior for one condition (one VI 60-s VI 20-s condition), 
and less problem behavior was observed than would be predicted for the other conditions 
(VI 20-s VI 60-s, and one VI 60-s VI 20-s condition). Similar results were observed for 
the programmed reinforcer method of calculation (Panel E) as in the last response method 
of calculation, and the proportional rates of problem behavior were correlated with the 
proportional reinforcement rates for problem behavior (r = .41), although during a 
number of sessions, more problem behavior was observed than would be predicted based 
on the proportional rate of reinforcement for problem behavior. For the most part, these 
sessions were those during which more reinforcement was available for appropriate 
behavior relative to problem behavior (VI 60-s VI 20-s). The means for each condition 
using the programmed reinforcer method of calculation (Panel F) also show that the 
relative rate of responding was correlated with the relative rate of reinforcement (r = .95), 
however, more problem behavior was observed than would be predicted based on the 
proportional rate of reinforcement for problem behavior during conditions with more 
reinforcement available for appropriate behavior (i.e., VI 60-s VI 20-s), and less problem 
behavior was observed than would be predicted for the conditions during which more 
reinforcement was available for problem behavior (i.e., VI 20-s VI 60-s).
Figure 3-6 shows the results from Equation 1-2 for Greg during the escape condition. Generally, for the last response method of calculation (Panel A), the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior, however the best fit line does not indicate close adherence to matching ($r^2 = .30$). The means for each condition using the last response method of calculation (Panel B) also show that the relative rate of responding was correlated with the relative rate of reinforcement, and the best fit line indicated adherence to the matching equation ($r^2 = .60$). The slope for both panels was less than 1.0, which suggests that undermatching occurred. For the within 10-s method of calculation (Panel C), the proportional rates of problem behavior were closely correlated with the proportional reinforcement rates for problem behavior, and the best fit line indicated matching ($r^2 = .85$). The means for each condition using the within 10-s method of calculation (Panel D) also show that the relative rate of responding was positively correlated with the relative rate of reinforcement, and the best fit line indicated matching ($r^2 = .88$). The slope for both panels was less than 1.0, which suggests that undermatching occurred. For the programmed reinforcer method of calculation (Panel E), the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior, however the best fit line did not approximate perfect matching ($r^2 = .22$). The means for each condition using the programmed reinforcer method of calculation (Panel F) also show that the relative rate of responding was correlated with the relative rate of reinforcement, and the best fit line indicated strict adherence to the matching equation ($r^2 = .69$). The slope for both panels was less than 1.0, which suggests that undermatching occurred.
Figure 3-7 shows the results from the matching analysis of the tangible condition using Equation 1-1 for Audrey. Generally, for the last response method of calculation (Panel A), the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior ($r = .79$), however for a number of sessions, more problem behavior was observed than would be predicted based on the proportional rate of reinforcement for that response. The means for each condition using the last response method of calculation (Panel B) also show that the relative rate of responding was positively correlated with the relative rate of reinforcement ($r = .98$).

During the conditions with a higher rate of reinforcement for appropriate behavior (VI 60-s VI 20-s) slightly more problem behavior was observed than would be predicted based on the proportional rate of reinforcement for problem behavior. Generally, for the within 10-s method of calculation (Panel C), the proportional rates of problem behavior were closely correlated with the proportional reinforcement rates for problem behavior ($r = .87$), with the points falling close to the line indicating perfect matching. The means for each condition using the within 10-s method of calculation (Panel D) also show that the relative rate of responding was correlated with the relative rate of reinforcement ($r = .95$).

Similar results were observed for the programmed reinforcer method of calculation (Panel E) as in the previous methods of calculation, and the proportional rates of problem behavior were positively correlated with the proportional reinforcement rates for problem behavior ($r = .72$). The means for each condition using the programmed reinforcer method of calculation (Panel F) also show that the relative rate of responding was positively correlated with the relative rate of reinforcement ($r = .96$).
Figure 3-8 shows the results from Equation 1-2 for Audrey during the tangible condition. Generally, for the last response method of calculation (Panel A), the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior, however the best fit line does not indicate matching \((r^2 = .23)\). The means for each condition using the last response method of calculation (Panel B) also show that the relative rate of responding was correlated with the relative rate of reinforcement, and the best fit line did not indicate adherence to the matching equation \((r^2 = .28)\). The slope for both panels was less than 1.0, which suggests that undermatching occurred. For the within 10-s method of calculation (Panel C), the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior, and the best fit line indicated matching \((r^2 = .84)\). The means for each condition using the within 10-s method of calculation (Panel D) also show that the relative rate of responding was positively correlated with the relative rate of reinforcement, and the best fit line indicated almost perfect matching \((r^2 = .99)\). The slope for Panel C was less than 1.0, which suggests that undermatching occurred. Generally, for the programmer reinforcer method of calculation (Panel E) the proportional rates of problem behavior were positively correlated with the proportional reinforcement rates for problem behavior, however the best fit line did not approximate perfect matching \((r^2 = .44)\). The means for each condition using the programmed reinforcer method of calculation (Panel F) also show that the relative rate of responding was correlated with the relative rate of reinforcement, and the best fit line matching \((r^2 = .86)\). The slope for both panels was less than 1.0, which suggests that undermatching occurred.
Figure 3-9 shows the results from the matching analysis of the escape condition using Equation 1-1 for Alice. Generally, for the last response method of calculation (Panel A) the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior ($r = .77$), however for a number of sessions, more problem behavior was observed than would be predicted based on the proportional rate of reinforcement for that response. The means for each condition using the last response method of calculation (Panel B) also show that the relative rate of responding was correlated with the relative rate of reinforcement ($r = .77$). For the within 10-s method of calculation (Panel C), the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior ($r = .75$), however, during some sessions more problem behavior was observed than would be predicted based on the proportional rate of reinforcement for problem behavior. The means for each condition using the within 10-s method of calculation (Panel D) also show that the relative rate of responding was correlated with the relative rate of reinforcement ($r = .84$). For the programmed reinforcer method of calculation (Panel E), similar results were observed as in the previous methods of calculation, and the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior ($r = .71$). The means for each condition using the programmed reinforcer method of calculation (Panel F) also show that the relative rate of responding was correlated with the relative rate of reinforcement ($r = .84$).

Figure 3-10 shows the results from Equation 1-2 for Alice during the tangible condition. Generally, for the last response method of calculation (Panel A), the proportional rates of problem behavior were correlated with the proportional
reinforcement rates for problem behavior, however the best fit line does not indicate matching \( (r^2 = .25) \). The means for each condition using the last response method of calculation (Panel B) also show that the relative rate of responding was correlated with the relative rate of reinforcement, and the best fit line did not indicate matching \( (r^2 = .23) \). The slope for both panels was less than 1.0, which suggests that undermatching occurred. For the within 10-s method of calculation (Panel C), the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior, and the best fit line did not indicate matching \( (r^2 = .32) \). The means for each condition using the within 10-s method of calculation (Panel D) also show that the relative rate of responding was correlated with the relative rate of reinforcement, however, the best fit line did not indicate matching \( (r^2 = .01) \). The slope for both panels was less than 1.0, which suggests that undermatching occurred. Generally, for the programmed reinforcer method of calculation (Panel E) the proportional rates of problem behavior were correlated with the proportional reinforcement rates for problem behavior, however the best fit line did not approximate perfect matching \( (r^2 = .45) \). The means for each condition using the programmed reinforcer method of calculation (Panel F) also show that the relative rate of responding was correlated with the relative rate of reinforcement, and the best fit line did not indicate strict adherence to the matching equation \( (r^2 = .41) \). The slope for both Panel F was less than 1.0, which suggests that undermatching occurred.

Figure 3-11 provides examples from each participant depicting closer approximations to matching towards the end of a condition. Each figure has been discussed above and shown with the results for each participant. However in Figure 3-11
the first and last sessions of a condition are noted with an arrow for each participant. Panel A shows the results using the within 10 s method of calculation for Greg’s tangible analysis during the second VI 20-s VI 60-s phase. In the last session of the condition, the proportional rate of responding more closely approximates the proportional rate of reinforcement relative to the first session in that condition. Panel B shows the results using the last response method of calculation for Audrey’s tangible analysis during the second VI 10-s VI 10-s phase. Again, in the last session of the condition, the proportional rate of responding more closely approximates the proportional rate of reinforcement relative to the first session in that condition. Panel C shows similar results using the within 10 s method of calculation for Greg’s escape analysis during the second VI 20-s VI 60-s phase. Finally, Panel D shows similar results using the last response method of calculation for Alice’s escape analysis during the first VI 60-s VI 20-s phase.

In summary, results of the matching analysis indicated that, for all participants the relative rates of both problem behavior and appropriate behavior were sensitive to the schedules of reinforcement available for each alternative. In addition, interventions were implemented and successfully decreased levels of problem behavior to clinically acceptable levels. Further, evaluation of the results from a matching perspective using both the simple matching equation (1-1) and the generalized matching equation (1-2) indicated that for all participants, relative rates of problem behavior were positively correlated with the relative rate of reinforcement for problem behavior. Results of this investigation suggest that the matching law can provide an explanation for problem behavior exhibited by individuals with developmental disabilities. While “perfect matching” was not obtained, matching is a steady state phenomenon and all participants
were exposed to the various conditions only briefly, and positive correlations were observed. One possible explanation may be that the early sessions in each condition represent a transition period, during which the participant begins to discriminate between the concurrent schedules of reinforcement, and that stable responding occurs towards the end of each condition. A comparison of the session-by-session scatter plots and the mean scatter plots suggests that closer approximations to matching were observed by calculating the mean of the last five sessions of each condition than calculating all sessions in each condition. This effect was observed for all participants.

For Alice, we were not able to complete a thorough assessment given the time constraints of her hospitalization. However, while additional sessions and replications would have provided further support for our findings, we did observe approximations to matching in a limited assessment. In addition, given the severity of Audrey’s problem behavior (i.e., SIB), we began her assessment with the treatment component, and were able to reduce problem behavior to clinically significant levels. We were then able to recommend a treatment package for use in the school and home settings while we continued to assess her problem behavior.
Figure 3-1. Overall response rates for problem and appropriate behavior for Greg.  A) Responses per min of problem and appropriate behavior during tangible sessions.  B) Responses per min of problem and appropriate behavior during escape sessions.
Figure 3-2. Overall response rates for problem and appropriate behavior during the assessment phase for Audrey and Alice.  A) Responses per min of problem and appropriate behavior for Audrey.  B) Responses per min of problem and appropriate behavior for Alice.
Figure 3-11. Scatterplots depicting examples of closer approximations to matching towards the end of the condition using the simple matching equation. Arrows show the first and last sessions within a condition. A) Results of the within 10s method for Greg’s tangible analysis during the second VI 20-s VI 60-s phase. B) Results of the last response method of calculation for Audrey’s tangible analysis during the second VI 10-s VI 10-s phase. C) Results of the within 10 s method of calculation for Greg’s escape analysis during the second VI 20-s VI 60-s phase. D) Results of the last response method of calculation for Alice’s escape analysis during the first VI 60-s VI 20-s phase.
In Experiment 1, functional analyses were conducted for problem behavior exhibited by three individuals diagnosed with developmental disabilities to identify reinforcers. For Greg, results suggested that screaming was reinforced by access to tangible items, and disruptive behavior was reinforced by escape from instructional demands. For Audrey, results suggested that SIB was reinforced by access to tangible items. Finally, for Alice, results suggested that aggression and disruption were reinforced by escape from instructional demands.

In Experiment 2, an analysis of concurrent reinforcement schedules was conducted with independent reinforcement schedules in place for both problem behavior and appropriate behavior in order to evaluate behavior from a matching perspective. For all evaluations, the relative rate of responding was influenced by the relative rate of reinforcement. Analyses for Greg during the tangible and escape conditions, and the analysis for Audrey during the tangible condition, provided closer approximations to matching than the limited analysis for Alice. Finally, in Experiment 2, full treatment evaluations were conducted to reduce problem behavior to clinically significant levels. DRA was implemented with EXT to increase appropriate behavior for all participants. For all evaluations, DRA and EXT were successful in reducing problem behavior and increasing appropriate behavior.

The matching law has been shown to be a useful way of describing response allocation across a variety of subjects (e.g., Baum, 1974a, 1974b; Beardsley &
McDowell, 1992; Conger & Killeen, 1974; Crowley & Donahoe, 2004; Herrnstein, 1961, 1975; MacDonald, 1988) for an array of response topographies (Borrero & Vollmer, 2002; Martens & Houk, 1989; McDowell, 1981; Symons et al., 2003), and across nonexperimental (Symons et al., 2003; Vollmer & Bourret, 2000) and experimental (Mace et al. 1994; Neef & Lutz, 2001; Neef, Mace & Shade, 1993; Neef, Shade & Miller, 1994) arrangements.

In order to evaluate the matching relation, the rates of responding for problem and appropriate behavior were calculated, as well as the rates of reinforcement for problem and appropriate behavior. One notable difficulty involves defining a “reinforced response.” It is not always clear how responses are reinforced, even with a schedule of reinforcement in place. Therefore, three calculations were included to account for possible differences in results based on the way in which a reinforced response was defined. One method of calculation was the last response method, during which the response that occurred immediately prior to the delivery of a reinforcer was the only response considered to be reinforced. This calculation accounted for sequential relations between a response and a known reinforcer. A second calculation was the within 10-s method, during which any response that occurred 10 s before a reinforcer was delivered was considered to be a reinforced response. This calculation accounted for temporal relations between a response and a known reinforcer. Finally, a third calculation was the programmed reinforcer method, during which a response for which a reinforcer was delivered according to the programmed schedule of reinforcement was considered to be a reinforced response. This calculation accounted for the delivery of programmed.
reinforcers according to the schedule in place. It is not clear which calculation is the most useful, although some differences between the calculations were observed.

In order to evaluate the differences between calculation methods, correlation coefficients ($r$) and coefficients of determination ($r^2$) were evaluated. Table 4.1 shows, for all participants, the results of the data analysis using the simple matching equation (Equation 1-1) and the generalized matching equation (Equation 1-2), for all calculation methods (i.e., last response method, within 10-s method, and programmed reinforcer method). The results for all calculations are summarized in Table 4.1, for both the session-by-session and mean analyses, with the closest approximations to matching shown in bold. For each method of calculation, four values are shown for the correlation coefficients and the coefficients of determination, resulting in 8 possible values for each coefficient. For 4 of 8 calculations, the last response method provided the larger correlation coefficients, for 4 of 8 calculations, the within 10 s method provided the larger correlation coefficients (the last response and within 10 s methods were equal for one calculation), and for 2 of 8 calculations, the programmed reinforcer method provided the larger correlation coefficients. The largest coefficients of determinations were obtained using the within 10-s method for 4 of 8 calculations, the programmed reinforcer method for 3 of 8 calculations, and the last response method for 1 of 8 calculations. These results suggested that all methods of calculation supported an interpretation of the data from a matching perspective, and results may vary depending on the definition of a reinforced response.

A second difficulty may be that, such analyses are quite time-consuming, and may be difficult to conduct when working with individuals who engage in severe problem
behavior. It may not be possible to conduct such lengthy analyses due to the severity of problem behavior (e.g., severe SIB and aggression), particularly when such an analysis delays the implementation of an intervention. Audrey’s assessment may provide an alternative strategy for conducting thorough analyses, by evaluating a treatment prior to conducting the matching analyses. It is possible that evaluating the full treatment component prior to the assessment of concurrent schedules could reduce some of the difficulties associated with evaluating severe problem behavior from a matching perspective. Designing a treatment package prior to a more lengthy assessment may alleviate some of the clinical concerns (e.g., continued risk of injury due to SIB) raised by parents and careproviders. For example, following the development of an effective treatment, parent and careprovider training could be conducted, and the treatment could be implemented in a timely manner outside of the experimental context.

The present experiments suggest areas for future research. This analysis included various concurrent schedules of reinforcement for problem and appropriate behavior. Evaluating concurrent schedules of reinforcement may be useful, as it is likely that in the natural environment, reinforcers are available for both problem and appropriate behavior at the same time but with varying probabilities. Future research may conduct similar analyses using concurrent schedule arrangements based on naturalistic observations. For example, descriptive analyses (Bijou, Peterson, & Ault, 1968) could be conducted with parents and careproviders and the results could be analyzed using reinforcers identified in a functional analysis (Iwata et al. 1982/1994) with procedures similar to those described by Borrero and Vollmer (2002). For example, if descriptive analysis data showed that problem behavior was reinforced on a VI 20-s schedule, and appropriate behavior was
reinforced on a VI 40-s schedule, experimental analyses could be designed to mimic naturally occurring reinforcement rates in an experimental context. Concurrent schedules of reinforcement could be based on the derived schedules of reinforcement observed during naturally occurring situations, and a subsequent matching analysis could be conducted. The extent to which relative response allocation is similar under both descriptive and experimental arrangements may provide greater support for the generality of the matching relation. Matching analyses may also suggest critical values of reinforcement parameters that may increase both the acceptability and integrity of treatment implementation by primary caregivers in the natural environment. It is often difficult and perhaps unrealistic to train parents not to provide reinforcement following problem behavior. Matching analyses may suggest the lower limit of caregiver reinforcement that may be provided while maintaining clinically acceptable levels of appropriate behavior (Vollmer, Roane, Ringdahl, & Marcus, 1999).

An additional area of future research may also include analyses of various parameters of reinforcement. Previous research (Borrero, Vollmer, Borrero, & Bourret, 2005; Mace et al., 1994; see Stromer, McComas, & Rehfeldt, 2000 for a comprehensive review) has suggested that duration of reinforcement (Dixon et al., 1998; Fisher, Piazza, & Chiang, 1996; Peck et al., 1996) delay to reinforcement (Neef et al., 2005; Neef et al., 1994; Vollmer, Borrero, Lalli, & Daniel, 1999), quality of reinforcement (Neef, Bicard, & Endo, 2001; Neef & Lutz, 2001; Mace et al., 1996) and magnitude of reinforcement (Hoch, McComas, Johnson, Faranda, & Guenther, 2002; Lerman, Kelley, Vorndran, Kuhn, & LaRue, 2002; Volkert, Lerman, & Vorndran, 2005) are important variables for evaluating response allocation, in addition to rate of reinforcement. Investigations similar
to these just cited could be conducted with any of the additional parameters of reinforcem
forcement by holding constant rate of reinforcement. In addition, the implications for the
treatment of severe problem behavior may be significant. Often, problem behavior is so se
vere (e.g., head-banging on hard surfaces, severe aggression, etc.) that it is not possible to withhold reinforcement (i.e., extinction). That is, especially in the case of behavior reinforced by attention, it is not possible to ignore the behavior, and some attention (e.g., blocking the response) will likely be necessary to ensure the safety of the individuals in the situation. However, it may be possible to manipulate other reinforcem parameters such as duration or quality of reinforcement.

One limitation of these experiments may be the small number of concurrent schedule values. For Greg and Alice, we only manipulated two values for the concurrent schedules. For Audrey, we manipulated three values however, we did not conduct a thorough analysis of the third value, nor did we conduct a reversal to that phase (i.e., VI 60-s VI 20-s was assessed for only three sessions). Future research may also include parametric schedule value evaluations. For example, the schedules could initial start with a VI 20-s for problem behavior and VI 60-s for appropriate behavior, and then values in between (e.g., VI 25-s VI 55-s) until the schedules are switched (i.e., VI 60-s VI 20-s). Such evaluations may be useful in quantifying reinforcer value by identifying indifference points (i.e., values which differ quantitatively but produce indifferent response allocation).

A second limitation of these experiments may be the brevity of the conditions. In a basic preparation, it may be possible to conduct conditions until meeting a stability criterion (e.g., a difference of less than 5% between data points), however, in the applied
setting, it was not always possible to bring each condition to stability before exposing behavior to another condition (i.e., Alice). Therefore, the matching analyses conducted in these experiments may not be based on stable responding, and this could account for some of the variability observed. This may be supported by the observation of closer approximations to matching towards the end of each condition. Ideally, for all participants, each set of conditions would have been conducted until meeting stability criteria.

The present experiments focused on evaluating the rate of reinforcement and the effects on problem and appropriate behavior. It was designed to determine if the simple matching equation (1) and the generalized matching equation (2) provided descriptions of response allocation on concurrent schedules of reinforcement with three individuals with developmental disabilities who engaged in severe problem behavior.
Table 4-1. Summary of correlation coefficients (r) for all participants using the Simple Matching Equation and the coefficients of determination using the (r^2) Generalized Matching Equation.

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LIST OF REFERENCES


Lerman, D. C., Kelley, M. E., Vorndran, C. M., Kuhn, S. A. C., & LaRue, R. H., Jr.


BIOGRAPHICAL SKETCH

Carrie S. W. Borrero was born in Easton, Pennsylvania, in 1973 to Donald and Santa Wright, and grew up in Bethlehem, Pennsylvania. Carrie attended the University of Pittsburgh, and in 1995 graduated with a Bachelor of Science degree in psychology. In 1997, she entered the graduate program in counseling and human services at Villanova University in Pennsylvania. Carrie was awarded her Master of Science degree in 1999. She then entered the graduate program in psychology (behavior analysis) at the University of Florida.