RESTRICTED AND REPETITIVE BEHAVIOR IN AUTISM SPECTRUM DISORDER: AN EXAMINATION OF FUNCTIONAL SUBTYPES AND NEUROPHYSIOLOGICAL FEATURES

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To my mother who taught me the value of education.

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ABSTRACT

Restricted and repetitive behavior (RRB) is a core feature of autism spectrum disorder (ASD). Research suggests that the severity of RRB may be influenced by both environmental variables (e.g., absence of sensory stimulation input) and neurophysiological activity within the body (e.g., atypical regulatory capacity of the autonomic nervous system). Substantial research efforts have been devoted to the assessment of factors that influence the occurrence of RRB in individuals with ASD, which have led to the development of assessment methodologies, such as functional analysis, to identify specific contexts in which RRB occurs, and measures of heart rate variability (HRV) to index the level of neurophysiological activity for individuals with ASD.

However, despite the increasing consensus that the assessment and treatment of RRB require a more comprehensive approach due to the complexity and heterogeneity of the neurodevelopmental disorder, there exists a paucity in research that addresses both the functional behavioral and neurophysiological dimensions of RRB. This study aimed to address this gap by (a) designing and evaluating the effects of an integrated function-based assessment on identification of the functional subtypes of RRB and (b) examining the relationship between RRB and HRV as an indicator of neurophysiological functioning. The study included six participants, ages four to seven, with ASD. A single-case alternating treatments design, with two conditions simulating low- and high-stimulation environments, was used for the assessment of functional subtypes within each participant. Dependent variables included the duration of RRB and HRV. RRB was measured using MOOSES, a multi-option observation system for experimental studies. HRV was measured using wearable technology that collects blood volume pulse. Visual analysis of time series data as well as nonparametric analyses of the dependent variables were conducted to determine the functional subtypes of RRB and the association between HRV and RRB across participants.

Study results suggest that (a) the integrated assessment is effective in identifying specific functional subtypes of RRB and (b) HRV is positively correlated with the rate of RRB. The findings of this study offer new insights on the understanding of how underlying environmental and neurophysiological mechanisms may influence the occurrence of RRB in ASD. Furthermore, the study provides an integrated assessment model that can be feasibly implemented in applied settings.

CHAPTER 1: INTRODUCTION

Autism and Restricted and Repetitive Behavior

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by features in two domains, social communication impairments and restricted and repetitive behaviors (RRB; American Psychiatric Association, 2013). Social communication impairments may include persistent deficits in social emotional reciprocity, nonverbal communicative behavior, and developing or maintaining social relationships across multiple contexts (American Psychiatric Association, 2013). RRB may include stereotyped motor movements or speech, ritualistic patterns of verbal or nonverbal behavior, highly restricted interests, and hyper- or hypo-reactivity to sensory input (American Psychiatric Association, 2013). RRB can be identified before two years of age (Fakhoury, 2015; Guthrie et al., 2013) and tend to persist and increase in severity over time (Guthrie et al., 2013; Matson et al., 2010). These challenging behaviors are often the cause of increased physical risks, social exclusion, more restrictive educational placement, and long-term use of psychotropic medications (Matson et al., 2010).

Etiology of Restricted and Repetitive Behavior

Behavior Analytic Perspective

Assessments and treatments based in the science of applied behavior analysis have been identified as evidence-based practices for improving behavioral outcomes in individuals with ASD (Boyd et al., 2012; Matson & LoVullo, 2008; National Autism Center, 2015; Watkins et al., 2019; Wong et al., 2015; Hume et al., 2021). However, compared to the amount of evidence for interventions that address social communication needs, the evidence base for the treatment of RRB is relatively scarce (Boyd et al., 2012). Thus, there remains a need for the expansion of evidence in assessing and treating RRB in ASD.

From a behavior analytic perspective, RRB are operant behaviors that may be maintained by social or nonsocial consequences that follow the behavior, including (a) social positive reinforcement, (b) social negative reinforcement, (c) automatic positive reinforcement, and (d) automatic negative reinforcement (Durand & Carr, 1987; Kennedy et al., 2000; Rapp & Vollmer, 2005). Behaviors maintained by positive reinforcement occur for the purpose of accessing reinforcers mediated by another person, such as social attention or preferred objects or activities (i.e., social positive reinforcer) or for the purpose of accessing reinforcers that cannot be mediated by another person, such as auditory, visual, vestibular, or tactile stimulation (i.e., automatic positive reinforcer). In contrast, behaviors maintained by negative reinforcement occur for the purpose of avoiding or escaping aversive stimuli mediated by another person, such as task demands (i.e., social negative reinforcer), or for the purpose of avoiding aversive stimuli that cannot be mediated by another person, such as body ache (i.e., automatic negative reinforcer; Kennedy et al., 2000; Lovaas et al., 1987).

Variables that influence challenging behavior can be identified through a functional analysis (FA), which identifies contingencies that maintain the target behavior through analyzing its relationship with environmental events (Hanley et al., 2003; Iwata, Dorsey, et al., 1994). As variables that maintain RRB may vary across individuals, it is typically necessary to assess them through an FA (DiGennaro Reed et al., 2012). In a traditional FA (Iwata, Dorsey, et al., 1994), participants are repeatedly exposed to four conditions, including: (a) a social positive reinforcement condition where social attention is withheld until target behavior occurs and then provided contingent on every occurrence of target behavior, (b) a social negative reinforcement condition where task demands are presented until target behavior occurs and then provided contingent on every occurrence of target behavior, (c) an automatic reinforcement condition where the participant is alone with the absence of any social contingencies, and (d) a control condition, where the participant is given unrestricted access to unstructured play activities with moderate social attention and no task demands regardless of the occurrence of target behavior (Iwata, Dorsey, et al., 1994). The function of a target behavior can be determined based on examining patterns of behavior within and across all conditions in the FA (Hagopian et al., 1997). Typically, a higher rate of target behavior in one condition relative to other conditions indicates the behavior is maintained by the reinforcer accessible in that particular condition (Roane et al., 2013).

It has been established in the behavior analytic literature that automatic reinforcement is the most prevalent function of stereotypic behaviors (Beavers et al., 2013; Rapp & Vollmer, 2005). There has been substantial effort devoted to the reduction of RRB in individuals with ASD over the past three decades based on the science of applied behavior analysis (DiGennaro Reed et al., 2012). However, the nonsocial function of repetitive behavior poses a challenge in the design of treatment for automatically reinforced behavior as the variables maintaining the behavior cannot be controlled by another individual.

Studies that attempted to address repetitive behaviors maintained by automatic reinforcement have primarily relied on procedures that manipulate social consequences, such as tangible objects or attention, or punishment procedures that rapidly reduce stereotypic behavior (Rapp & Vollmer, 2005). When treatments are aimed at suppressing specific forms of RRB rather than addressing the function, they may result in increases in other forms of RRB that are not targeted in the treatment (Lanovaz & Sladeczek, 2012).

Furthermore, when automatic function is identified through an FA, it is typically indicated by either elevated levels of the target behavior in the alone condition in contrast with the other conditions or elevated levels of target behavior in all conditions (Querim et al., 2013). As there is no attention or items that have the potential to serve as social and physical stimulation in the environment created in the alone condition, any behavior that occurs at a high rate in this condition can be said to be positively reinforced by the consequence produced directly by the behavior itself (Iwata, Dorsey, et al., 1994). A constraint of this model of assessment commonly used to identify automatically reinforced behavior is the inability to differentiate positive and negative reinforcement even when an automatic function is identified.

Consequences of behavior maintained by automatic reinforcement cannot be manipulated by another individual unless the behavior is suppressed or the sensory stimulation produced by the behavior is masked (e.g., Dorsey et al., 1982). Unlike the attention and escape conditions in an FA, where social stimuli can be presented or removed as an immediate consequence of the occurrence of target behavior, automatic reinforcers cannot be presented or removed by another individual contingent on the target behavior. However, it is possible to manipulate the value of the reinforcer or consequence through antecedent events as FA methodology provides a means for the manipulation of motivating operations (MOs) in addition to discriminative stimuli and relevant consequences of a target behavior (Hanley et al., 2003; Lydon et al., 2012).

MO refers to a stimulus event or condition that alters the value of reinforcers or punishers and the frequency of behavior responses that are associated with the reinforcers or punishers in effect (Laraway et al., 2003). MO can be further classified based on its effects on consequences and behaviors. In relation to its value-altering effect on reinforcers or punishers and behavior-altering effect, MO can be classified as either an establishing operation or an abolishing operation, which has an evocative or abative effect on behaviors respectively (Langthorne & McGill, 2009). In the context of FA methodology and automatically maintained behavior, the concept of MOs provides a framework for describing the relationship between antecedent events and their effects on behavior.

In a traditional FA, the alone condition consists of a “relatively barren environment” with no programmed stimulus as antecedent or consequence (Iwata & Dozier, 2008). When the environment provides minimal sources of stimulation, an individual in that environment is deprived of stimulation, and thus the value of stimulation increases. This creates an establishing operation for behaviors that have been associated with access to stimulation. Therefore, behaviors that occur at elevated levels in the alone condition relative to other conditions are determined to be maintained by positive reinforcement rather than negative reinforcement, which aligns with the conceptualization of automatically maintained behavior as self-stimulatory behavior (Lovaas et al., 1987; Vollmer, 1994). Yet recent research suggests that RRB such as self-injurious behavior may occur due to either automatic positive or negative reinforcement (Hagopian et al., 2015). While this notion has not been experimentally demonstrated through behavior analytic methodologies due to difficulties in the manipulation and measurement of automatic reinforcers, an emerging body of research has begun to explore measures typically used in other sciences (e.g., physiological variables) to inform our understanding of the functional properties of behavioral symptoms of ASD including RRB (e.g., Baker et al., 2018; Lydon et al., 2015).

Neurophysiological Perspective

In the neurobiological literature, the Polyvagal Theory has been posited to explain the core phenotypic features of ASD. The Polyvagal Theory conceptualizes atypical social behavior and stereotypical behavior to be the result of imbalanced neural regulation of the autonomic nervous system (ANS; Porges, 2003, 2005, 2007). The ANS is a division of the peripheral nervous system and works to maintain homeostasis primarily at a subconscious level. It can be further divided into two major branches, the parasympathetic and the sympathetic nervous system. The parasympathetic and sympathetic divisions may work together or independently of each other in response to the environment (Cacioppo et al., 1994), the former primarily serving to regulate the body’s resting functions and the latter serving to prepare bodily reactions to emergency or physical exercise (McCorry, 2007).

The Polyvagal Theory proposes that the vagus is a major component of the ANS and plays an integral role in the bidirectional feedback between the brain and visceral organs (Porges, 2003). In typical conditions, the vagal brake is engaged and the parasympathetic nervous system maintains minimal physiological arousal through suppressing cardiac activity. When aversive stressors are present in the environment, the vagal brake is released and sympathetic activity dominates to produce physiological arousal through increasing cardiac activity (Porges, 2005, 2007). Efficient control of the vagal brake enables effective modulation of arousal by rapidly increasing or decreasing heart rate, hence enabling a typically developing individual to produce appropriate social behavior, such as rapid engagement and disengagement with people or objects. When the vagal brake is not efficiently controlled, it may compromise typical social behavior to promote other defensive and regulatory behavior (Porges, 2007).

The Polyvagal perspective attributes social impairments and RRB in ASD to dysregulation of the ANS, and this perspective is supported with some empirical evidence. Previous research has shown that compared to typically developing (TD) individuals, individuals with ASD tend to be over-aroused or under-aroused even at resting state when environmental stimuli evoke minimal stress (e.g., Anderson & Colombo, 2009; Mathersul et al., 2013). Studies have also shown that individuals with ASD regulate their arousal differently in response to different types or intensities of sensory stimuli in daily environment (i.e., over-reactive or under-reactive; Boyd et al., 2010; Liss et al., 2006). A recent review conducted by Benevides and Lane (2015) found that while existing literature does not show agreeable findings on whether there are differences in resting autonomic arousal of individuals with ASD compared to TD individuals, patterns of parasympathetic activation in response to challenging tasks are different between individuals with ASD and TD individuals. Findings of the review suggest that core features of ASD, including deficits in social communication and RRB, may be manifestations of atypical responsivity to environmental stimuli at the autonomic level (Benevides & Lane, 2015).

Measuring ANS Activity and Behavior in ASD

Autonomic arousal can be indexed through various measures, such as skin conductance (Lang, 1995), pupillary size (Anderson et al., 2006), salivary cortisol (Anderson et al., 2013), and heart rate variability (HRV; Miu et al., 2009). There is substantial evidence to support the association between externalizing symptoms of ASD and autonomic dysregulation indicated by these physiological measures (Lydon et al., 2016). For example, Schoen and colleagues (2009) examined skin conductance and sensory profiles of children with and without ASD and found significant differences in both measures (Schoen et al., 2009). Another study conducted by Condy and colleagues (2017) found significant associations between lower respiratory sinus arrhythmia, a measure of HRV, and more severe social communication impairments and RRB (Condy et al., 2017).

Similar with most empirical research in the psychological and biobehavioral literature, behavioral symptoms of ASD are often measured through indirect measures such as caregiver-report questionnaires (e.g., Matsushima et al., 2016) or behavior rating checklists based on perceived intensity or severity (e.g., Woodard et al., 2012). While there is a broad literature base that supports the use of standardized rating scales to index behavioral symptoms of ASD (e.g., Sensory Profile, Social Communication Questionnaire), it is difficult to interpret the results of these behavioral measures in the exact context in which physiological arousal is observed and measured. To address this gap, a small but emerging body of research has begun to develop multi-method assessments to collect both physiological and direct behavioral data as indicators of arousal and challenging behavior (Lydon et al. 2013; Moskowitz et al., 2013, 2017). In these studies, the collection of direct behavioral data involved operational definitions of the target behavior and quantitative measurement of the target behavior based on direct observation.

Achieving reliable quantification of behavior through utilizing operationalized definitions of behavior and accurate measurement systems is one of the core dimensions of applied behavior analysis (Baer et al., 1968). Widely used systems include event- and interval-based recording systems (Cooper et al., 2020). Event recording measures the frequency a behavior over a specific period of time and provides a true measure of observable behavior; interval recording estimates the duration or number of occurrences of behavior over a specific observation period (Lane & Ledford, 2014). While human errors may result in variation in precision and reliability of data recording, behavioral data obtained from direct observations offer an opportunity for researchers to identify specific environmental conditions in which the behavior occurs rather than making inferences regarding the context based on indirect observations (i.e., interviews, questionnaires). The current study will contribute to the emerging research by utilizing multiple methods of assessments to collect behavioral and physiological data simultaneously.

Integrating Perspectives

Research related to the origin of RRB has grown across various disciplines, yet the work on RRB has mostly been done within each field and in isolation from other fields (Leekam et al., 2011). Leveraging our understanding of the behavioral characteristics of ASD from sciences other than the science of behavior analysis may provide an additional lens for examining the mechanisms of ASD symptoms. The Polyvagal Theory, as well as existing empirical support for this theory, allows us to hypothesize that individuals with ASD may engage in RRB for the purpose of regulating their physiological arousal due to dysregulation of their ANS. This allows for the conceptualization of automatic reinforcement not as the undifferentiated or unknown function of a behavior with consequences that cannot be observed or measured, but rather as a function that may be isolated by supplementing data of behavior responses with physiological indicators of arousal.

This proposed study aims to address the following research questions: (a) Can RRB maintained by automatic reinforcement be differentiated into positive and negative reinforcement? (b) Is there an association between physiological arousal and severity of automatically maintained RRB? To address the first question, the study will attempt to differentiate automatic positive and automatic negative reinforcement by utilizing, in part, the assumption that manipulating the antecedent (i.e., amount of stimulation from the environment) can evoke behavior maintained by automatic positive or automatic negative reinforcement. It is hypothesized that consistently higher rates of RRB in a traditional alone condition indicate the behavior is maintained by automatic positive reinforcement. It is also hypothesized that if higher rates of RRB are observed in a condition that simulates an environment with elevated levels of stimulation, it is an indication the behavior is maintained automatic negative reinforcement. However, as the consequence of automatically reinforced behavior is not accessible to an experimenter, measurement remains a challenge. For example, access to social positive reinforcer in an attention condition can be measured in several dimensions, such as frequency, rate, and latency. On the other hand, automatic reinforcers cannot be measured in these dimensions through traditional behavioral measurement observation and recording systems. Drawing on theoretical perspective and measurement techniques from the neurophysiological field may provide a means for indexing the automatic reinforcer. Therefore, this study seeks to address the second research question through obtaining simultaneous measures of RRB and HRV.

CHAPTER 2: LITERATURE REVIEW

Autism and Restricted and Repetitive Behavior

When Leo Kanner (1943) first described what we now know as core characteristics of autism spectrum disorder (ASD), a substantial portion of the narrative focused on features in the restricted and repetitive behavior (RRB) domain. Much of the description provided in his seminal article remains accurate today (Mesibov et al., 2000) and has been used to define core symptoms of ASD based on the latest DSM-5 criteria (American Psychiatric Association, 2013). For example, “echolalia” was used to describe the repetition of other people’s speech, “repetitiousness” of “verbal utterances” were used to describe vocal stereotypy, “insistence on sameness” was used to describe resistance to unpredictable situations and strong persistence in maintaining routines (Kanner, 1943). These dimensions of RRB have been examined extensively by researchers with a wide range of expertise.

Researchers have studied the etiology of RRB in the context of ASD across disciplines, resulting in different interpretations of factors contributing to RRB and implications for the approach to treating RRB. Research in cognitive psychology generally attributes RRB to impairments in executive functioning, which lead to errors or inflexibility in responses when there is an unanticipated shift of rules in rule-based tasks (e.g., Agam et al., 2010; Lopez et al., 2005; Uddin et al., 2015). Research in developmental psychology interprets the manifestation of RRB as a product of variation in developmental trajectories of individuals with ASD (e.g., Lord et al., 2012; Moore & Goodson, 2003). The research in this field has collectively made great strides in utilizing caregiver-reported or clinically observed RRB to advance diagnostic tools of ASD for infants and young children (e.g., Autism Diagnostic Observation Schedule, Second Edidtion, ADOS-2, Lord et al., 2012; Social Communication Questionnaire, SCQ, Rutter et al., 2003). In neurophysiology, researchers have studied RRB through experiments grounded in the perspective that there is a bidirectional interaction between biological functions and behavioral responses (e.g., Hirstein et al., 2001; Wang et al., 2016). When RRB is inspected from the perspective of behaviorism, RRB is shaped by the environment and its cause varies depending on the observed consequence produced by the behavior (Cunningham & Schreibman, 2008; Scheithauer et al., 2017).

The exploration of causes of RRB in each discipline has helped advance the science in assessing and treating RRB in individuals in ASD, yet little has been done to integrate different theoretical perspectives in the study of RRB (Leekam et al., 2011). The current chapter aims to provide a review of studies that have contributed to the RRB literature from two different theoretical perspectives, behavior analysis and neurophysiology. Study findings will be described and interpreted in relation to the etiology of RRB in the context of ASD. In addition, this chapter will identify strengths and gaps of the evidence base in each field and describe how the proposed study will attempt to address these gaps.

Behavior Analytic Approach

On the grounds of behavior analysis, behaviors are maintained by operant mechanisms, with exceptions such as elicited responses (i.e., reflexive behavior) and responses as a result of spasms or seizures (Vollmer, 1994). Behavior is learned through the process of operant conditioning and reinforcement plays a key role in this process (Skinner, 1948). A behavior is either reinforced or punished based on whether its consequence increases or decreases future occurrences of the behavior. The repetitive feature of RRB implies that it produces consequences that are reinforcing to the individual engaging in RRB. In early behavior analytic literature, attempts to identify the reinforcers of RRB resulted in diverging conclusions (Durand & Carr, 1987; Rapp & Vollmer, 2005)

Lovaas and colleagues (1987) conceptualized stereotyped and repetitive behavior as "self-stimulatory behavior" and "functionally autonomous". They posited that RRB persists even when there are no socially mediated consequences because it is maintained by perceptual stimuli that are automatically generated by the behavior (Lovaas et al., 1987). The term "perceptual stimuli" was used to describe what an individual sees, hears, or feels physically when engaging in a behavior. In their article, examples associated with atypical object manipulations and vocal or motor stereotypies commonly observed in individuals with ASD were used to illustrate the concept of perceptual reinforcers. For example, repeatedly lining up toys in a manner that is irrelevant to the context may produce a preferred visual pattern; body-rocking or head-nodding may produce vestibular stimulation that is preferred to the lack of such stimulation when the body is still. The authors proposed that based on their conceptualization of RRB as a behavior that serves to access perceptual reinforcers, it is critical that we examine the perceptual characteristics of the reinforcers in order to strengthen or weaken the perceptual consequences maintaining the RRB.

In the same year, Durand and Carr (1987) published an article that investigated the function of RRB in four children who were diagnosed with autism or pervasive developmental disorder and concluded that RRB such as hand-flapping, body-rocking, self-injurious behavior, and out-of-context vocalization may serve a social function. Their study utilized a withdrawal single-case experimental design to determine if the presence or absence of social reinforces would evoke different levels of RRB. They identified a negative social reinforcement function in the target repetitive behavior across all four participants through analyzing behavior patterns under repeated exposure to positive, negative, or no social reinforcement in different study phases. The authors also further confirmed the function of the participants' behavior by evaluating the effects of a treatment that allowed the participants to access negative reinforcement (i.e., escape from difficult tasks) through appropriate communication (i.e., the phrase "Help me"). Treatment results demonstrated that the participants' stereotyped behaviors were maintained by negative reinforcement and reduced to near zero levels when they received negative reinforcement through requesting for assistance with difficult tasks. The authors of this study refuted the hypothesis that stereotyped and repetitive behavior can all be termed "self-stimulatory" behavior and called for the use of function-based treatment contingent on empirically identifying the function of RRB rather than assuming an automatic or sensory function (Durand & Carr, 1987). With the development and dissemination of an analogue functional analysis (FA) protocol for self-injurious behavior by Iwata and colleagues (Iwata et al., 1982/1994), subsequent studies that attempted to determine the function of RRB have commonly utilized this procedure.

Functional Analysis

The conception of the analogue FA was spurred by the lack of effective and non-aversive treatment for self-injurious behavior in individuals with developmental disabilities due to insufficient understanding of the variables maintaining the behavior (Iwata, Dorsey, et al., 1994). The authors proposed that a rigorous methodology that more accurately identifies the environmental variables maintaining the behavior would assist in the selection of effective treatments based on the function identified instead of best guesses. In Iwata, Dorsey, et al. (1994), a multi-element experimental design was utilized to systematically manipulate the environmental variables across four conditions, attention (social positive reinforcement), demand (social negative reinforcement), alone (automatic reinforcement), and play (control). In the attention condition, participants had access to some toys and were told to play with the toys. Attention was provided in the form of statements of concern and disapproval (e.g., "Don't do that, you're going to hurt yourself") and brief, non-punitive physical contact (e.g., hand on shoulder) contingent on each occurrence of the target self-injurious behavior. In the demand condition, difficult tasks were presented every 5 s with the least amount of physical prompting required to guide the participants in task completion. Praise was provided for both prompted and independent task completion. Contingent on each occurrence of self-injurious behavior, the task was removed for 30 s and no attention as provided. In the alone condition, participants had no access to social attention, toys, task materials, or any other items that may serve as external reinforcement. No social consequences were implemented contingent on the occurrence of the target behavior. In the unstructured play or control condition, participants had free access to toys and no task demands were presented. Moderate attention in the form of brief praises and physical contact was provided every 30 s when no self-injurious behavior occurred. Self-injurious behavior was ignored unless it was too severe, in which case the session would be terminated.

Based on the manipulation of contingencies in these FA conditions, visual analysis of participant responding across conditions inform conclusions regarding the functional properties of the target behavior. For example, if the level, trend, and variability of a participant's behavior is differentiated in the attention condition compared to all other conditions, with elevated occurrences of behavior observed in the attention condition, the participant's target behavior is most likely maintained by social positive reinforcement. Likewise, if a participant's target behavior is distinctly higher in the demand condition than all other conditions, the behavior is most likely maintained by social negative reinforcement. If the participant's target behavior is much higher in the alone condition relative to other conditions, the behavior is most likely maintained by automatic reinforcement. If a participant's behavior is undifferentiated and at high levels across all conditions, it is possible that the behavior is maintained by multiple variables or variables not controlled in the experiment, or the stimuli manipulated in the conditions were not sufficiently salient to the participant to evoke the target behavior (Iwata, Dorsey, et al., 1994).

The results of Iwata, Dorsey, et al. (1994) demonstrated that distinct functional patterns could be identified across participants regardless of disability category (e.g., intellectual disability, autism, blindness, hearing impairment) and topography of self-injurious behavior (e.g., eye gouging, hair pulling, head hitting, self-biting). Although the authors implemented this protocol with children and adolescents who were diagnosed with a range of developmental and physical disabilities not limited to ASD and addressed only one type of RRB (i.e., self-injurious behavior), the analogue FA has been further replicated across behavior topographies and disability populations, and settings by other research groups (Querim et al., 2013). Despite widespread use of the analogue FA methodology (Iwata, Dorsey, et al., 1994) to identify behavioral functions and subsequently facilitate the development of function-based interventions to treat challenging behavior (Beavers et al., 2013; Hanley et al., 2003), some limitations exist.

Automatic Reinforcement

Functional analysis procedures for identifying an automatic function allows experimenters to make the conclusion that behavior maintained by automatic reinforcement is positively reinforced rather than negatively reinforced (Iwata & Dozier, 2008). As described above, the alone condition of the FA was designed to simulate an environment that is void of external reinforcers that may provide additional social stimulation to the individual. Therefore, behaviors that consistently occur in the alone condition should serve to obtain stimulation that was not present in the environment. No condition in the FA was designed to simulate an environment that may evoke behavior that serves to escape aversive nonsocial stimuli. Yet, some behavioral research suggests that automatic reinforcement may be further classified into positive and negative reinforcement.

Iwata, Pace, and colleagues (1994) subcategorized the reinforcing stimuli of automatically maintained self-injurious behavior in 39 individuals with developmental disabilities by identifying patterns in their FA data with considerations of behavior topography and medical history. Seven out of 39 participants displayed high and undifferentiated levels of self-injurious behavior across FA conditions, and were therefore included in the automatic reinforcement category with the reasoning that their reinforcing stimuli were likely not external and thus could not be controlled by the experimenters. The remaining 32 participants had elevated levels of self-injurious behavior in the alone condition compared to all other conditions. However, in two of the cases, scratching was the primary behavior topography and these participants had histories of allergic and dermatologic problems. The authors concluded that these two participants might be engaging in self-injurious behavior for the purpose of pain or discomfort attenuation, which could be interpreted as automatic negative reinforcement (Iwata, Pace, et al., 1994). Their conclusion aligns with some researchers who have also proposed that automatically reinforced behavior may serve to reduce pain or physical discomfort (i.e., negative reinforcement) in addition to accessing favorable stimulation (i.e., positive reinforcement; Carr & McDowell, 1980; Cataldo & Harris, 1982; Fisher & Iwata, 1996; Vollmer, 1994).

Despite recognizing the potential divergence of function within automatic reinforcement, our knowledge of automatically reinforced behavior has remained limited over several decades due to the challenge in empirically identifying and manipulating the sources of reinforcing stimuli for these behaviors (Hagopian et al., 2015; Ringdahl et al., 2008). To address this paucity, a recent study conducted by Hagopian and colleagues (2015) attempted to delineate subtypes of automatically maintained self-injurious behavior in individuals with ASD and/or intellectual disability by analyzing FA data from published studies. They analyzed 39 cases of automatically reinforced self-injurious behavior in a sample of individuals between the ages of 3 to 21 years old and developed three behavioral subtypes based on visual inspection of their FA data. The subtypes included: (a) sensory, (b) strong sensory, and (c) mixed sensory.

In Subtype 1 (i.e., sensory stimulation), self-injurious behavior is highest in the alone condition and lowest in the play condition with a clear differentiation, which implies that the behavior produces reinforcing sensory consequences when no other reinforcing stimuli are available in the environment. In Subtype 2 (i.e., strong sensory stimulation), self-injurious behavior is high and variable across all FA conditions, with mean rate of SIB at 50 responses per min or more in both play and alone conditions, and with 30% or more overlap of data between alone and play conditions. Meeting these criteria implies that the behavior produces reinforcing stimuli that are higher in magnitude or quality than any stimuli present in the environment, and thus the behavior occurs at high levels regardless of the noncontingent stimulation provided in the play condition. In Subtype 3 (i.e., mixed sensory stimulation), self-restraint behavior is present in at least 25% of intervals across three sessions in the alone condition, implying that the self-injurious behavior produces both desirable sensory and pain. For this subtype, self-restraint may serve as a discriminative stimulus for negative reinforcement by obstructing self-injurious behavior and thus removing the pain or discomfort produced by self-injurious behavior.

Further analyses of treatment effectiveness across the three subtypes provided preliminary evidence that individuals with different subtypes of self-injurious behavior may respond differently to treatment (Hagopian et al., 2015). Specifically, for majority of the participants categorized as Subtype 1, interventions consisting of solely reinforcement-based procedures were implemented with largely positive outcomes. For Subtype 2 participants, a variety of interventions were implemented including, from most to least implemented, reinforcement alone, multiple-components, punishing or blocking or restraint, and protective equipment. However, none of the reinforcement alone interventions yielded positive outcomes, whereas other categories of interventions yielded mixed outcomes. For Subtype 3 participants, restraint or protective equipment was utilized with positive outcomes across all participants.

Hagopian and colleagues (2015) also replicated the major findings of this study by examining a larger sample of studies published by other research groups (Hagopian et al., 2017). The findings of these studies suggest that automatically reinforced self-injurious behavior in individuals with ASD and/or intellectual disability may be further differentiated into subtypes to inform the selection of treatment components.

In favor of the hypothesis that automatic reinforcement may also be negatively reinforcing, a study conducted by Richards and colleagues (2017) examined the predictors of self-injurious behavior and found a significant association between the presence of painful health problems and the presence and severity of self-injurious behavior in a sample of 208 children with ASD (Richards et al., 2017). While findings of this study did not establish a functional relation between pain and self-injurious behavior, it lends support to the idea that RRB, which may include self-injurious behavior topographies, may serve either or both automatic positive reinforcement and automatic negative reinforcement (e.g., removes pain or discomfort caused by skin problems) in individuals with ASD.

In spite of the emerging body of research that attempts to address the underlying mechanisms of automatically reinforced behavior, automatic reinforcers are not accessible to external agents (Ringdahl et al., 2008). This poses a challenge in the functional assessment process as experimenters are not able to systematically measure and manipulate the reinforcing stimuli. In social FA conditions, attention and task demands are systematically added or removed contingent on the occurrence of the target behavior, which allows experimenters to establish experimental control and derive functional relations between the social reinforcer and the target behavior when consistent patterns are observed. On the other hand, as automatic reinforcers are not observable by or accessible to others, quantifying the frequency, duration, latency, magnitude, or topography of an automatic reinforcer through behavior analytic measurement system is an issue. Additionally, majority of the functional analysis literature that examined automatically reinforced behavior has largely focused on self-injurious behavior (Beavers et al., 2013), which is only a subset of the possible topographies of RRB (Bishop et al., 2013; Lam & Aman, 2007). In order to address this gap, the proposed study seeks to utilize theoretical perspectives and techniques from a different discipline to examine variables that maintain automatically reinforced RRB not limited to self-injurious behavior.

Neurophysiological Approach

Autonomic Nervous System

In the broader psychological sciences, the presence of RRB in ASD has been conceptualized as a biological mechanism resulting from atypical neural development and functions in individuals diagnosed with ASD. Specifically, the Polyvagal Theory proposes that ASD symptoms can be attributed to the dysregulation of the autonomic nervous system (ANS; Porges, 2003, 2005, 2007). The ANS is part of the peripheral nervous system and serves to regulate functional states of visceral organs and maintain homeostasis. It can be divided into two major branches, including the parasympathetic nervous system (PNS) and sympathetic nervous system (SNS), which may function co-actively or independently based on environmental demands. Generally, the body's "rest-and-digest" functions are regulated through the activation of the PNS, while "fight-or-flight" functions are regulated through SNS activity (Berntson et al., 1991; Cacioppo et al., 1994).

Based on the Polyvagal Theory, vagal control is a key component of ANS functioning. The vagus nerve includes both afferent and efferent fibers, involving bidirectional feedback to and from the brainstem in the regulation of cardiac functioning (Beauchaine, 2001). In the context of a natural environment with typical stimuli that do not evoke stress, increased vagal influence leads to the activation of the PNS, which suppresses cardiac activity. In this physiological state, heart rate is relatively slower and appropriate social engagement behavior is more likely to occur. When the environment presents stimuli that are novel, unpredictable, or stressful, it evokes the withdrawal of vagal influence, which increases SNS activity (Friedman, 2007). Activation of the

SNS results in a faster heart rate, which indicates a higher level of autonomic arousal, and facilitates behaviors in response to stressor stimuli.

With respect to ASD symptoms, the Polyvagal Theory postulates that the physiological state (i.e., autonomic arousal) impacts the capacity of an individual in the engagement of social communicative behavior, which is central to the difficulties that individuals with ASD have (Porges, 2007). Typically developing individuals are able to control the extent of vagal influence in a manner that allows for effective pacing of the heart and thus more efficient regulation of physiological arousal. On the other hand, the ANS of individuals with ASD is compromised and the resulting inefficient modulation of physiological arousal manifests as atypical characteristics in the domains of social communications and RRB (Liss et al., 2006; Mathersul et al., 2013; Porges, 2003, 2007).

In line with this theory, a substantial body of empirical literature has shown that arousal in individuals with ASD tend to be dysregulated compared to TD individuals (e.g., Anderson & Colombo, 2009; Condy et al., 2017; Guy et al., 2014; Van Hecke et al., 2009). However, autonomic activity has a temporal dimension which can be classified into tonic and phasic, and there is yet to be a consensus on whether phenotypical features of ASD are primarily associated with atypical tonic or phasic arousal, or both.

Tonic and Phasic Arousal

Tonic activity of the ANS refers to baseline or resting activity; phasic activity of the ANS refers to changes at a point in time or over a period of time typically in response to a stimulus change (Wass et al., 2015). Tonic and phasic activity may occur independently or interdependently of each other, and may also occur in a reciprocal or nonreciprocal manner (Berntson et al., 1991; Cacioppo et al., 1994). Thus, the number of ways tonic and phasic arousal interact with each other adds complexity to how they can be studied or indexed separately. However, prior research suggests that tonic arousal is primarily influenced by the sympathetic division of the ANS, whereas phasic arousal is primarily influenced by the parasympathetic division of the ANS (Porges, 2007; Wass et al., 2015).

This temporal distinction in ANS activity serves as a basis for the interpretation of arousal levels in the context of ASD. For instance, some studies conclude that individuals with ASD have the tendency to be chronically over-aroused or under-aroused compared to TD individuals based on significant differences they found in overall baseline (i.e., tonic) levels of arousal between the two population groups (e.g., Anderson & Colombo, 2009; Mathersul et al., 2013). Other studies suggest that individuals with ASD are characterized by different magnitudes of change in arousal level in response to various stimulus changes (i.e., phasic), which may indicate over-reactivity or under-reactivity (Boyd et al., 2010; Liss et al., 2006). Such mixed findings across the literature could be due to various factors, such as variability in experimental design and differential sensitivity of selected measures to tonic or phasic arousal (Benevides & Lane, 2015).

Heart Rate Variability

Autonomic Arousal and Heart Rate Variability

Researchers have explored several indices of autonomic arousal, such as pupil size, electrodermal activity (EDA), and heart rate variability (HRV), all of which are influenced by ANS activity (Wass et al., 2015). These indices have been utilized in ASD samples fairly extensively to identify the relationship between autonomic arousal and phenotypical features of ASD (Sinéad Lydon et al., 2016). In particular, HRV is recognized as a relatively direct indicator of ANS functioning that is sensitive across a range of physiological arousal (Friedman, 2007; Karemaker, 2017; Wass et al., 2015).

Heart rate variability refers to changes in the length of each interval between two consecutive heartbeats (Malik, 1996). In each heartbeat cycle, the sinoatrial node, which is comprised of a group of specialized cells, produces electrical impulses spontaneously. The initiation of electrical impulses is controlled by autonomic nerves; the rate of initiation increases with SNS activity and decreases with PNS activity (Becker, 2006). As a result of sinoatrial node depolarization, each heartbeat cycle forms a QRS complex when it is recorded on a typical electrocardiogram (ECG). Simple temporal measures of HRV may be derived through various ways, such as calculating the difference in RR interval (interval from one R-peak to the subsequent R-peak) between each QRS complex of a heartbeat, between the longest and shortest RR interval, or between heart rate at various times of a day (Malik, 1996).

In addition, statistical metrics of HRV have also been developed to more accurately capture HRV under different contexts. For example, the standard deviation of normal intervals (SDNN) has been proposed to be representative of HRV over short-term periods, with conventional recording standard at 5 min (Malik, 1996). The root mean square of successive differences between normal heartbeats (RMSSD) is another measure that has been used predominantly to reflect vagally mediated changes in HRV, with appropriate observation periods ranging from 10 s, 5 min, or more. An advantage of RMSSD is that it has been found to be less affected by changes in respiration (Hill et al., 2009), which is typically assessed through respiratory sinus arrhythmia (RSA). RSA indicates heart rate differences between inhalation and exhalation, which typically increases and decreases heart rate respectively. This change in heart rate primarily reflects the outflow of neural activity from the PNS to the heart (Hill et al., 2009). It is worth noting that the connection between RMSSD and the PNS is stronger than that with the SNS, which may affect the interpretation of RMSSD analyses with respect to ANS functioning (Shaffer & Ginsberg, 2017).

Heart Rate Variability and ASD

Prior research has examined the deviation in HRV between ASD and TD samples and provided some empirical evidence that individuals with ASD do not maintain typical levels of autonomic arousal. For instance, Van Hecke et al. (2009) investigated tonic and phasic physiological activity in children with and without ASD through assessing RSA, a measure of HRV. Participants consisted of 28 children with ASD and 16 TD children. They were asked to sit and view a blank screen for 3 min while baseline RSA is measured, followed by tasks involving the viewing of a 5-min video showing an unfamiliar person reading a story, another 5-min video showing a familiar caregiver reading a story, and a 5-min video playing classical music and moving objects. The authors found robust differences in both the overall RSA (tonic) across all conditions, and reactivity RSA (phasic) in response to novel stimuli (i.e., videos of unfamiliar persons) between the two groups of participants (Van Hecke et al., 2009).

A more recent study that examined the RSA of children with ASD and their age- and IQ-matched TD controls found significantly lower baseline (tonic) RSA in individuals with ASD (Neuhaus et al., 2014). Another study conducted by Guy et al. (2014) included a socially challenging task that required participants to engage in a reciprocal conversation with a clinician based on a visual prompt (e.g., picture of a beach) to examine potential differences in phasic RSA in addition to tonic RSA. The ASD group demonstrated significantly lower RSA than the TD group during the social task (Guy et al., 2014). These studies provide evidence that individuals with ASD tend to have reduced tonic and phasic HRV relative to TD individuals, which implies that dysregulation of the ANS is present in ASD.

Measures of Behavioral Symptoms of ASD

Besides differences in arousal in comparison to TD individuals, researchers have also attempted to determine if the extent of atypical ANS dysregulation mediates the severity of ASD symptoms. To address this question, there is a growing body of literature that examined the relationship between arousal and behavioral symptoms of ASD. However, the literature in this area does not present consistent findings, with some studies finding significant associations between measures of ASD symptoms and autonomic arousal, and other studies finding a lack thereof.

Matsushima et al. (2016) examined high frequency HRV (HF-HRV) in a sample of 37 children with ASD and 32 TD children between the ages of 6 to 12 years old. In addition to finding significantly lower resting HF-HRV in the ASD sample compared to the TD sample, they also found a significant correlation between lower resting HF-HRV and (a) lower scores in the visual/auditory sensitivity section of the Short Sensory Profile (SSP; McIntosh, Miller, Shyu, & Dunn, 1999), (b) higher scores in the restricted interests and repetitive behavior subscale of the Social Responsiveness Scale 2 (SRS-2; Constantino, 2012), and (c) lower scores in the social motivation subscale of the SRS-2. These findings suggest that more severe visual/auditory hyper-reactivity, more severe RRB, and less active social interaction behavior in children with ASD could potentially be attributed to the dysregulation of arousal in response to unpredictable sensory or social stimuli in the environment (Matsushima et al., 2016).

In alignment with the findings of Matsushima et al. (2016), several studies have found similar associations between measures of autonomic arousal and severity of ASD symptoms. For instance, Guy et al. (2014) found an association between HRV and socialization scores on the Vineland Adaptive Behavior Scales, Second Edition (VABS-2; Sparrow, Cicchetti, & Balla, 2005) in 14 children and adolescents with ASD with a mean age of 12 years old (Guy et al., 2014). Condy et al. (2017) found an association between HRV and social communication index on the SRS-2, and scores of stereotyped motor behavior subscale and sameness subscale reported on the Repetitive Behavior Scale-Revised (RBS-R; Lam & Aman, 2007) in children with ASD aged five to 10 years old (Condy et al., 2017). Fenning et al. (2017) found an association between EDA and

ASD symptoms indexed by the ADOS-2 (Lord, Rutter, et al., 2012) in children with ASD between the ages of four to 10 years old (Fenning et al., 2017).

In a more recent study conducted by Bazelmans et al. (2019), the authors examined HRV in a sample of preschool children, consisting of 71 children with ASD and 66 TD children. Interestingly, they found no significant differences in resting HRV between ASD and TD groups when the children were presented stimuli in the form of four 90-s video of wildlife animals with classical music in the background. However, they found that higher HRV was significantly associated with better receptive and expressive language skills indicated on VABS-2 among the children with ASD (Bazelmans et al., 2019). The results of these studies support the hypothesis that the extent to which ASD features are externalized as observable behaviors may correspond with their capacity for regulating physiological arousal.

Contrary to these findings, Patriquin et al. (2013) examined RSA and social and language skills in 23 young children with ASD between the ages of four to seven years old and found no significant association between tonic RSA and SRS total and subscale scores (Patriquin et al., 2013). Smeekens et al. (2015) investigated autonomic measures including HRV and salivary cortisol in a sample of 16 adults with ASD and 19 adults without ASD. Resting state arousal data were obtained when the participants read a book or magazine for a period of 18 min pre-task and 16 min post-task, whereas task arousal data were obtained when the participants engaged in role play of social situations with an unfamiliar person for 3 min (i.e., greeting and providing information to a new neighbor, calling a landlord regarding an unrepaired facility). Their performance in the social task was assessed through the Social Skills Performance Assessment (SSPA; Patterson et al., 2001). Results of this study showed that adults with ASD demonstrated comparable tonic and phasic HRV with their TD controls.

These mixed findings in the literature suggest that broad measures of ASD symptoms might not be sufficiently sensitive to behaviors that relate to the dysregulation of physiological arousal (Klusek et al., 2015). Moreover, although several widely used measures of ASD symptomology (e.g., RBS-R, SRS-2, SSP) have been validated for indexing the severity of ASD across various domains, these measures are often administered with caregivers or teachers of participants with ASD. Through these measures, caregivers are essentially rating the behavioral symptoms based on their perception of the behaviors over a relatively long or undefined period of time (e.g., over the past one month for RBS-R, undefined for SRS and SP). A limitation of utilizing data obtained from these indirect measures is that they do not provide information about the environmental conditions or contexts in which RRB occur (Raulston & Machalicek, 2018). Hence, it is likely that these measures of behavioral symptoms may not be adequately reliable or accurate in indicating the severity of specific responses to correspond with direct measures of autonomic arousal administered within a specific condition or window of time.

Furthermore, while some studies have designed tasks that may evoke different social responses in individuals with ASD that can be directly observed and assessed simultaneously with autonomic arousal (e.g., Smeekens et al., 2015), behavioral responses observed during these tasks typically do not include RRB. Common tasks and data collection methods utilized in psychophysiology often require participants with ASD to maintain a state of physical inactivity (e.g., sitting in a chair with minimal movement) with relatively focused attention on a given task (Condy et al., 2017; Neuhaus et al., 2016; Schaaf et al., 2013; Watson, et al., 2012). As such, it is likely that participants who are not able to comply with the demands of these tasks would either be excluded entirely from study participation or be excluded from analyses due to the presence of motion artefacts in the data obtained. Therefore, conventional study designs in this field do not provide a means to capture RRB directly within experiments. This could be a reason that researchers in this field have relied largely on ratings and scores from caregiver-questionnaires or clinical assessments to index the universal presence and severity of RRB in an individual. To bridge this gap, some research has emerged to explore a multi-method approach to directly measure both observable behavioral responses and indicators of physiological arousal in individuals with ASD.

Integrated Approach

Conventional measures of RRB in psychological sciences have primarily involved rating scores on caregiver-report questionnaires (e.g., Baker et al., 2018; Condy et al., 2017; Neuhaus et al., 2016; Schaaf et al., 2013; Watson et al., 2012), which have the potential to capture the full range of RRB displayed by an individual across the day. Moreover, experimental conditions in a study are not likely to simulate all possible circumstances under which RRB may occur. However, such measures do not provide a means for the quantification and analysis of RRB in relation to the specific environmental context in which autonomic arousal is measured. On the other hand, conventional assessment of RRB based on the science of applied behavior analysis does not include systems for measuring automatic reinforcers. This prevents us from making conclusions regarding the positively or negatively reinforcing property of automatic reinforcers of RRB and impede the development of specific function-based treatments for RRB.

Researchers have thus begun to examine the relationship between RRB and arousal through more objective measures of RRB. For example, Jennett et al. (2011) investigated the relationship between arousal and self-injurious behavior in an adolescent with ASD and intellectual disability. The authors measured heart rate simultaneously with the rate of self-injurious behavior in individuals with ASD during sessions where arm restraint was either accessible or inaccessible to the participant. They found a functional relation between the presence of arm restraint and changes in heart rate, with increases in heart rate contingent on the removal of arm restraint and decreases in heart rate contingent on the application of arm restraint. They also implemented a physical activity condition, during which the participant was asked to engage in arm raising exercises that imitate the motions of her self-injurious behavior, to determine if the increase in heart rate was an artefact of physical activity. Their data suggest that elevated heart rate was primarily due to the occurrence of the target RRB rather than other physical behavior (Jennett et al., 2011).

Another study conducted by Lydon et al. (2013) also examined the relationship between heart rate and various forms of RRB in a sample of three children with ASD and intellectual and developmental disabilities. The authors did not find consistent patterns across the participants in terms of increases or decreases in heart rate 5 s prior to and 5 s after occurrences of their target RRB. The authors deduced that the participants' RRB were potentially maintained by multiple functions based on results of prior indirect assessments, which could have reduced the effect that their RRB had on increasing or reducing physiological arousal as the target behavior could have served multiple purposes (Lydon et al., 2013).

Moskowitz et al. (2013) examined the relationship between RSA and challenging behavior of children with ASD between the ages six to nine years old. The participants' challenging behavior were comprised of RRB such as repetitive questioning, vocal stereotypy, hand mouthing, or looking for a familiar person through the door or window. The authors utilized an alternating treatments design to evoke the target behaviors through counterbalancing test and control conditions. The test condition involved situations that were rated as high-anxiety by the participants' parents, including birthday parties, separating from parents, and car rides. The control condition involved play activities such as watching television, playing with balls, and playing a game. Two of the three participants demonstrated significantly reduced RSA in the test condition, while the remaining one participant approached significance in the association between RSA and condition (Moskowitz et al., 2013). Subsequently, Moskowitz and colleagues (2017) developed an intervention package for these same participants in a later study and examined their target behavior and RSA as well.

In the intervention study, the authors utilized a nonconcurrent multiple-baseline design across participants to evaluate the effects of an intervention that involved a combination of antecedent-based and consequence-based strategies, including visual schedules, social stories, priming, providing choices, generalized reinforcement, incorporating perseverative interests, differential reinforcement of alternative behavior, and escape extinction (Moskowitz et al., 2017). Based on the data presented, RSA did not appear to change significantly contingent on the introduction of intervention. Nonetheless, this study, among a few others, contributes to an emerging body of research that explores a multi-method approach to assessing RRB in individuals with ASD.

In summary, integrating behavior analytic and neurophysiological perspectives may serve to address the limitations of the literature from each field. Conventional behavior analytic assessments of RRB do not include a protocol for differentiating automatic positive versus automatic negative reinforcement partly due to a lack of measurement system to quantify automatic reinforcers. However, the technique of operationally defining and directly measuring observable behavior is a feature of behavior analysis that can be coupled with physiological measures of unobservable behavior such as autonomic arousal to determine the presence or absence of a functional relation between the two variables. To bridge this gap, the proposed study aims to (a) delineate positive and negative reinforcement that is automatically maintaining RRB through implementing a modified functional analysis and including simultaneous measures of HRV, and (b) examine the relationship between RRB and HRV within and across subjects.

CHAPTER 3: METHODS

Research Questions and Hypotheses

The current study aimed to answer the following research questions: (a) Can RRB maintained by automatic reinforcement be delineated into automatic positive and automatic negative reinforcement through a modified functional analysis? (b) Do behavior patterns based on the modified FA correspond with different arousal profiles in individuals with ASD?

The purpose of the study was to delineate automatic positive and automatic negative reinforcement by varying the antecedent (i.e., amount of stimulation from the environment) to evoke behavior maintained by automatic positive or automatic negative reinforcement. It was hypothesized that (a) higher rates of RRB in the silent (low-stimulation) condition indicate a behavioral function of automatic positive reinforcement, (b) higher rates of RRB in the noise (high-stimulation) condition indicate a behavioral function of automatic negative reinforcement, and (c) undifferentiated rates of RRB across both silent and noise conditions indicate a behavioral function of mixed automatic reinforcement. The study also examined the association between RRB and physiological arousal through simultaneous measures of observable behavior and heart rate variability (HRV) during the modified FA. It was hypothesized that HRV would be associated with the rates of RRB.

Participants and Setting

Participant Characteristics

Study participants were recruited from two autism clinics in suburban Midwestern United States. Both clinics provided intensive applied behavior analysis (ABA) services to children diagnosed with ASD. Participants were recruited based on a protocol approved by the institutional review board. Potential participants who met the following inclusion criteria were identified via referrals from clinic administrators and supervisory staff: (a) presence of medical or educational diagnoses of ASD made by independent parties (e.g., physicians, psychologists), (b) age between 3 to 12 years old, and (c) daily occurrences of observable RRB such as vocal or motor stereotypic behaviors. Examples of observable RRB may include but were not limited to out-of-context speech or sounds and repeated movement of head, body, or limbs. Potential participants with severe self-injurious behavior or other behaviors that may harm others were excluded from the study. After identifying potential participants, a consent packet including the following documents were sent via email or in paper to the caregivers of the potential child participants: (a) a letter to caregivers describing the purpose of the study, (b) an informed consent form for caregivers, (c) a child assent form, (d) a modified child assent form for non-verbal children, and (e) a private health information release authorization form. Eight participants were initially included in the study based on clinic administrator referrals and caregiver consents provided. However, two of the participants were excluded from further participation in the study. One of the excluded participants turned 13 years old after study enrollment, while the other participant underwent major changes in treatment routines at the clinic that did not allow for time to participate in the study. A total of six children ultimately participated in this study. Table 1 shows an overview of participant demographics including age, sex, disability or medical diagnosis, medication, and the topography of RRB measured.

Table 1. Participant Demographics

Name	Age	Sex	Disability/Medical Diagnosis	Medication	Target RRB
Cassie	6	Female	ASD; sensory disturbance; developmental delay; seizure disorder (nocturnal epilepsy)	Clobazam, Famotidine, Keppra, Levetiracetam, Prednisone	Vocal and motor
Greta	4	Female	ASD	-	Vocal
Roger	4	Male	ASD; epilepsy; global developmental delay; seizure disorder	Keppra	Vocal and motor
Marc	7	Male	ASD	-	Vocal
Griffin	7	Male	ASD	-	Vocal
Aubrey	5	Female	ASD	-	Vocal and motor

Note. ASD = autism spectrum disorder; RRB = restricted and repetitive behavior. Participant names are pseudonyms. Participant ages are ages at study enrollment.

Cassie

Cassie was a six-year-old White female. She was diagnosed with ASD, sensory disturbance, and developmental delay at two years seven months of age by a pediatrician at a university-affiliated hospital for children. Cassie also had seizure disorder in the form of nocturnal epilepsy. Medications that Cassie took over the course of the study included Levetiracetam, Prednisone, Famotidine, Keppra, and Clobazam. Cassie's caregiver completed the Vineland Adaptive Behavior Scales, Third Edition (VABS-3; Sparrow et al., 2016) when Cassie was five years six months of age. VABS-3 is a standardized questionnaire that assesses the extent an individual engages in everyday life behaviors compared to same-age peers. There are three domains of adaptive behavior included in VABS-3: Communication, Daily Living, and Socialization. The Communication domain measures an individual's receptive, expressive written communication skills; the Daily Living domain measures an individual's personal, domestic, and community behaviors; the Socialization domain measures interpersonal, play and leisure, and coping skills. Cassie's composite score on VABS-3 was 67 (percentile rank = 1) and subscale scores were 67 (percentile rank = 1) for the Communication domain, 65 (percentile rank = 1) for the Daily Living domain, and 66 (percentile rank = 1) for the Socialization domain. These scores indicate that Cassie's overall level of adaptive behavior was at or above one percent of her same age peers.

Cassie received ABA services at an autism clinic each morning and attended a public preschool each afternoon, five days a week. She also received physical therapy, occupational therapy, and speech and language therapy through a service provider independent of the autism clinic. Cassie communicated vocally with one- to three-word utterances (e.g., "nap", "need help", "I want…"). She engaged in vocal stereotypic behavior including repeating words or phrases from songs, dialogues, or animated shows, and producing non-speech sounds (e.g., "mmm", "choochoo", "grr"). She also engaged in motor stereotypic behavior including rocking her body and flapping or rotating her hands.

Greta

Greta was a four-year-old White female. She was diagnosed with ASD at one year seven months of age by a doctoral-level psychologist who was also a certified health service provider. Her clinical records did not include a VABS evaluation. She had allergies that required the use of an inhaler but did not take medications during the course of the study. Greta received ABA services at an autism clinic 7 h a day, five days a week. Greta communicated vocally or through a speech generating device in one- to three-word utterances (e.g., “book”, “all done”, “I want…”). While her primary language was English, Greta also used American Sign Language for labeling and requesting. Greta engaged in vocal stereotypic behavior, such as repeating words or phrases from songs or animated shows and producing non-speech sounds (e.g., “bababa”).

Greta engaged in mild self-injurious behavior in the form of hitting her face with her hand. However, her self-injurious behavior was determined to be infrequent and relatively harmless and this she was deemed appropriate for study participation by her supervisory clinic staff. A termination criterion of “hitting her head or face against a hard surface” was set during study participation. If the termination criterion was met, the clinic staff implementing the study sessions could terminate a session and intervene with existing clinic safety protocol. The termination criterion was not met throughout the course of the study.

Roger

Roger was a four-year-old White male. He was diagnosed with ASD by a doctoral-level clinical psychologist and certified health service provider affiliated with the autism clinic he attended. Roger was also diagnosed with global developmental delay and epilepsy and took Keppra as a medication for his seizure disorder. Roger’s supervising therapist at the autism clinic evaluated his adaptive behavior using VABS-3 comprehensive caregiver form (Sparrow et al., 2016) when he was three years five months of age. His composite score on VABS-3 was 55 (percentile rank < 1) and his subscale standard scores were 40 (percentile rank < 1) for the Communication domain, 60 (percentile rank < 1) for the Daily Living domain, and 50 (percentile rank < 1) for the Socialization domain. These scores indicate that Roger’s overall level of adaptive behavior was below his same age peers.

Roger received ABA services 7 h a day, 5 days a week at an autism clinic. He also received 1 h of occupational therapy and 30 min of speech therapy per week at the clinic. Roger communicated primarily through hand gesturing or through one-word requests (e.g., “go”, “play” “bathroom”) on a speech generating device. He engaged in vocal stereotypic behavior in the form of producing non-speech sounds (e.g., “dee doo”, “pff”). He also engaged in motor stereotypic behavior including spinning his body, flapping his hands, repeatedly hitting a body part or object with his hand, hopping, pacing back and forth within an enclosed area without an observable purpose.

Roger engaged in self-injurious behavior in the form of hitting his head with an object or against another person. As his self-injurious behavior was relatively mild (i.e., not forceful) and typically did not occur frequently or for a long duration, Roger's participation in the study was deemed as appropriate by his supervisory clinic staff. To maximize his safety, a termination criterion of "continued engagement in self-injurious behavior for 1 min" was set during study participation. If the termination criterion was met, the clinic staff implementing the study sessions could terminate a study session and intervene with existing clinic safety protocol. Throughout the course of the study, none of Roger's study sessions had to be terminated.

Marc

Marc was a seven-year-old Hispanic male. He was diagnosed with ASD at four years five months of age by a doctoral-level clinical psychologist who was also a certified health service provider at a university-affiliated hospital for children. He did not have any other medical diagnoses and did not take any medication. His clinical records did not include a VABS evaluation. He received ABA services at an autism clinic 7 h a day, five days a week. He also received weekly speech therapy with a service provider independent of the autism clinic. Marc communicated vocally in phrases or sentences between three to eight words (e.g., "Go to the gym", "Are we done yet?"). Marc engaged in vocal stereotypic behavior such as vocalizing out-of-context speech, singing, and squealing. His out-of-context vocalization was often in the form of repeating or rephrasing lines from songs or dialogues (e.g., "see you later", "no more monkeys jumping on the bed").

Griffin

Griffin was a seven-year-old White male. He was diagnosed with ASD at two years eight months of age by a service provider independent of the autism clinic he attended. His clinical records did not include VABS-3 evaluation. He did not have other medical diagnoses and did not take any medications. Griffin received ABA services at an autism clinic 7 h a day, five days a week. He also received 30 min of speech therapy weekly at the clinic. Griffin communicated vocally in single words or short phrases (e.g., “I want…”). He engaged in vocal stereotypic behavior such as producing out-of-context speech or non-word sounds and squealing. When his vocal stereotypic behavior involved repeating words or phrases from shows he had watched, the vocalization may be accompanied by some imitative hand gestures. However, these hand gestures were not considered to be motor stereotypic behavior due to the lack of observable repetitive patterns in occurrence.

Aubrey

Aubrey was a five-year-old White female. She was diagnosed with ASD at two years one month of age by a pediatric neurologist at a university-affiliated hospital. She had a history of chronic ear infections and had pressure equalization tubes in her ears since she was two years five months old. Her clinical records did not include a VABS evaluation. Aubrey received ABA services 7 h a day, five days a week at an autism clinic, including 1 h of speech therapy each week. She communicated either through a speech generating device or vocally using single words or short phrases (e.g., “yes”, “no”, “go outside”, “I want push”). Aubrey engaged in vocal stereotypic behavior such as repeating lines from a song or dialogue and producing non-speech sounds. She also engaged in motor stereotypic behavior such as mouthing her hand, hair, or inedible objects, tapping her own shoulders, and flapping or rotating her hands.

Setting and Materials

Study sessions were implemented at the autism clinic where each participant received daily ABA treatment. Each room used for the study sessions included at least two tables and two chairs, with minimal other mobile furniture. All objects that were not relevant to the study were stored out of reach on a shelf or in closed containers. A wireless speaker was used to play noise during the noise condition of the study sessions. For Aubrey, whose modified FA included toy access, the toys used were stuffed princess dolls, laminated princess pictures, and glitter slime.

A clinic staff who worked one-on-one with each participant implemented all study sessions. The researcher, a doctoral student in Special Education, trained each clinic staff in implementing the study sessions and provided live instructions and feedback via video conference using a tablet during all study sessions. The staff used a video camera or tablet to video record each participant’s behavior in all study sessions. Using these recorded videos, data on target repetitive behavior were extracted post-session through a software, MOOSES™ (Multi-Option Observation System for Experimental Studies; Tapp et al., 1995). All participants wore an Empatica E4 wristband during study sessions to collect HRV data.

Dependent Variable Measurement and Interobserver Agreement

Restricted and Repetitive Behavior

The primary dependent variable was the total duration of target behavior occurrences within each 5-min session. The target repetitive behavior was measured in seconds through the MOOSES™ software (Tapp et al., 1995). In this software, the onset and offset of repetitive behavior could be recorded with 1 s as the smallest unit. For instance, if a target behavior was observed beginning from 1 min 20 s after the start of the session until 2 min 30 s of the session, the behavior was coded with a time-unit stamp of "on 80, off 150", indicating that the behavior started at the 80th second and ended at the 150th second of the session. The total duration per session the sum of the duration of each target behavior occurrence.

Interobserver agreement (IOA) data for the primary dependent variable was obtained across two independent observers for at least 33% of sessions (i.e., one randomly selected session out of three sessions) in the screening assessment and each condition of the modified FA. The primary observer was the researcher and the secondary observers included special education doctoral students who were trained in measurement systems of single-case research. Primary and secondary observers watched the video recordings of study sessions independently at different times and collected target behavior data based on written definitions each participant's target behavior. IOA between two observers was calculated through second-by-second comparisons (MacLean et al., 1985; Mudford et al., 2009). For each form of target behavior (i.e., vocal or motor), every second of the session was an opportunity for agreement or disagreement between two observers. In a 5-min session, the number of seconds (i.e., opportunities for agreement or disagreement) were 300. An agreement percentage was obtained for each target behavior through dividing the sum of number of seconds with agreement by 300 seconds. A mean IOA across sessions was calculated for the screening assessment and within each condition of the functional analysis for each participant, as shown in Table 2.

Table 2. Interobserver Agreement of Repetitive Behavior Measurement

Participant	Interobserver Agreement (%) Screening Assessment	Functional Analysis Silent Condition	Functional Analysis Noise Condition
Cassie	91 (81-99)	88 (78-100)	97 (92-100)
Greta	82 (74-92)	84 (81-89)	84 (80-88)
Roger	83 (79-86)	84 (79-96)	89 (79-100)
Marc	77 (70-85)	87 (82-90)	80 (72-83)
Griffin	83 (80-85)	83 (78-85)	81 (77-86)
Aubrey	94 (82-100)	97 (90-100)	99 (94-100)

Note. Values presented include a mean followed by a range in parentheses.

Heart Rate Variability

The secondary dependent variable was HRV within each 5-min FA session. An Empatica E4 wristband was used to collect photoplethysmography (PPG) signal, which is a measure of blood volume pulse (Allen, 2007). The PPG data were processed and converted into R-waves (i.e., visual representation of heartbeat cycles) using Kubios HRV software (Tarvainen et al., 2014). Loose fitting of the wristband on the wrist or forceful physical pressure on the wristband (e.g., knocking wristband on a hard surface) may cause inaccuracies in the PPG data collected and create artifact in the form of extra or missing heartbeats. Within the software, a medium threshold of 0.25 s for artifact correction was selected to identify incorrect interbeat intervals compared to the local average in each session. Subsequently, the identified artifact segments were replaced with interpolated values using cubic spline interpolation.

After artifact correction, HRV was calculated as the changes in the interbeat interval per session. Root mean square of successive RR interval differences (RMSSD) was obtained as an index of HRV within each 5-min modified FA session (Appelhans & Luecken, 2006; Silvetti et al., 2001). RMSSD is a temporal measure of HRV that has been documented to be relatively reliable for short-term recordings of heart rate (i.e., 5 min or less), less influenced by respiration, and more representative of the parasympathetic nervous system (Shaffer & Ginsberg, 2017).

Study Design and Procedures

A single case alternating treatments design (Barlow & Hayes, 1979) without baseline was used to compare the effects of the silent and noise conditions of the modified FA on the dependent variables. The two conditions were alternated within each day for majority of the days when study sessions were implemented. To minimize potential sequence effects, the alternating sequence was randomly determined through a random number generator, with even and odd numbers representing the two conditions respectively. If two consecutive sessions of the same condition were implemented, the subsequent session would be alternated to the other condition to prevent the implementation of three consecutive sessions of the same condition. For each participant, an average of two modified FA sessions were implemented per day, across 3 to 5 days a week. For the majority of the days, two sessions were implemented per day. On some of the days, one or three sessions were implemented based on the availability of the child participant and the clinic staff on a particular day. Therefore, the alternation between conditions sometimes occured across days instead of within a day if only one session was implemented on a particular day.

The purpose of the silent condition was to simulate a low-stimulation environment and evoke behavior maintained by access to stimulation; the purpose of the noise condition was to simulate a high-stimulation environment and evoke behavior maintained by escape from stimulation. If a participant engaged in higher levels of target repetitive behavior in the silent relative to the noise condition, the behavior was hypothesized to have an *automatic positive reinforcement* function. If a participant engaged in higher levels of target repetitive behavior in the noise relative to the silent condition, the behavior was hypothesized to have an *automatic negative reinforcement* function. If a participant engaged in similar levels of target repetitive behavior across the silent and noise conditions, the behavior was hypothesized to have a *mixed automatic reinforcement* function. If a participant engaged in minimal levels of target repetitive behavior in both conditions, the behavior was hypothesized to have a *social reinforcement* function instead of an automatic reinforcement function. An illustration of the study design and hypothesized subtypes based on the modified FA outcome is shown in Figure 1.

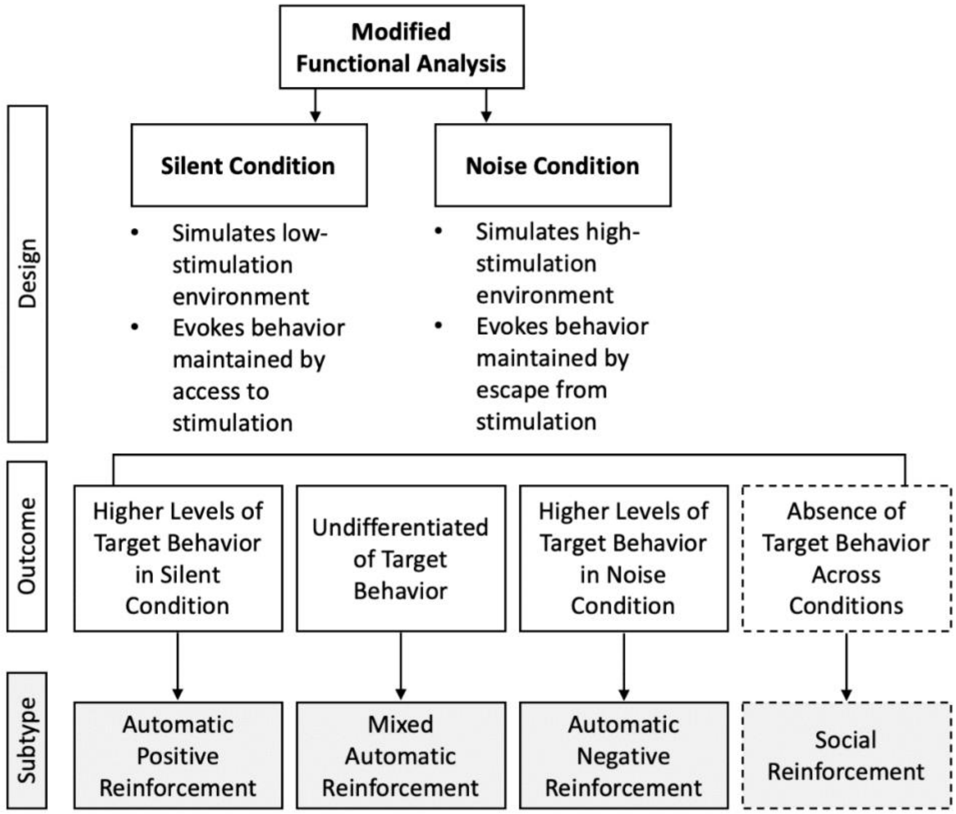

Figure 1. Study design and hypothesized outcomes with corresponding functional subtypes

Functional Assessment Interview

A brief functional assessment interview was conducted based on a protocol adapted from the Open-Ended Functional Assessment Interview (Hanley, 2012). The Open-Ended Functional Assessment Interview includes a set of 20 prompts and questions designed to identify potential factors that influence the occurrence of problem behavior. Typically, the interviewer is an external agent (e.g., behavior consultant) who is designing the assessment and/or intervention to address a focus individual's problem behavior, while the respondent is a natural agent (e.g., caregiver, teacher, therapist) who observes or interacts with the focus individual daily or frequently throughout a week. Interview questions are targeted at defining the problem behavior, identifying potential harm or danger that are associated with the problem behavior, and determining the most likely situations in which the behavior occurs. The information obtained from this interview may be used to inform the design of a functional analysis (e.g., conditions to implement, setting, session duration).

As this study aimed to examine repetitive behavior maintained by automatic reinforcement and did not aim to address problem behavior maintained by social reinforcement, the researcher adapted the questions from Hanley (2012) to specifically identify information related to a participant's repetitive behavior. The adapted interview prompts and questions used for this study are displayed in Table 3. The researcher conducted the interview with the supervising clinic staff of each participant after obtaining parental informed consent for study participation and parental authorization to release their child's clinical records and information to the researcher. Information obtained from the interview was used to develop operational definitions of each participant's target repetitive behaviors and hypothesize if automatic reinforcement was a probable function of the target behaviors. Based on the interview results, all six participants were hypothesized to have automatically reinforced repetitive behavior and thus continued to participate in the next phase of the study, the screening assessment.

Screening Assessment

After the functional assessment interview, a screening observational assessment based on the protocol described in Querim et al. (2013) was implemented to confirm if the function of each participant's target repetitive behavior was automatic reinforcement. Each observation session was 5 min in duration. Prior to the start of each session, the researcher asked the clinic staff to put away all instructional materials and toys in the room, if any, and to ensure that a speech generating device was present for participants who needed it as a primary means of communication. Then, the clinic staff assisted each participant in wearing the digital wristband and video recorded the participant from a distance throughout the session. The clinic staff was also instructed to withhold from socially interacting with the participant and ignore all participant behaviors, including mands and repetitive behaviors. If the participant attempted to take the wristband off or reach for other items in the room, the clinic staff was asked to physically block each attempt without speaking to the participant.

A checklist of the screening assessment procedures is displayed in Table 4 (items 1-10). At least five screening assessment sessions were implemented with each participant, or until a predictive pattern of data were obtained. If a participant's target repetitive behaviors persisted across the screening assessment sessions, the hypothesis that the behavior was maintained by automatic reinforcement would be confirmed, and thus the participant would continue to participate in the subsequent phase of the study, the modified FA. If a participant's target repetitive behavior did not persist in the screening assessment sessions, the hypothesis that the behavior was maintained by automatic reinforcement would not be confirmed, in which case the participant would be withdrawn from further participation in the study. However, none of the participants were withdrawn at this phase of the study as all six participants engaged in some extent of repetitive behavior across five to eight consecutive sessions.

Table 3. Functional Assessment Interview Questions and Prompts

Area	Questions/Prompts
Background information	1. Participant date of birth and gender 2. Language abilities 3. Play skills and preferred toys or leisure activities 4. Other preferences 5. Typical instructional activities
Target behavior	6. What are the repetitive behaviors observed? What do they look like? 7. Which behavior occurs most frequently?
Harmful behavior and precursors	8. Are any problem behaviors potentially harmful or dangerous? 9. What is the existing precautionary procedure? 10. Do different types of problem behavior occur in bursts or clusters, or does any type of problem behavior typically preceded another type of problem behavior to the harmful or dangerous behavior?
Antecedents of target behavior	11. Under what situations are the repetitive behaviors most likely to occur? 12. Do the repetitive behaviors occur when you break routines or interrupt activities?
Consequences of target behavior	13. How do you and others respond to the repetitive behavior? 14. What do you and others do to calm him/her down or distract him/her from the behavior? 15. Why do you think the child engages in the repetitive behaviors? Do you think the repetitive behaviors are a form of self-stimulation?

Note. Adapted from Hanley, G. P. (2012). Functional assessment of problem behavior: Dispelling myths, overcoming implementation obstacles, and developing new lore. *Behavior Analysis in Practice, 5*(1), 54–72.

Modified Functional Analysis

A modified FA adapted from the analogue FA (Iwata, Dorsey, et al., 1982/1994) was conducted with participants whose behavior data demonstrate an automatic reinforcement function based on the results of the screening assessment. The analogue FA developed by Iwata, Dorsey, and colleagues (1982/1994) consisted of four conditions including social disapproval (i.e., attention), academic task demand (i.e., escape), alone (i.e., ignore), and play. The attention condition was designed to evoke the occurrence of behavior maintained by social positive reinforcement; the task demand condition was designed to evoke the occurrence of behavior maintained by social negative reinforcement; the ignore condition was designed to evoke the occurrence of behavior maintained by automatic reinforcement the play condition was designed to serve as a control condition that should not evoke the occurrence of behavior maintained by social reinforcement.

In the modified FA of this study, the ignore condition from Iwata, Dorsey et al. (1982/1994) was adopted and shortened in duration (from 15 min to 5 min per session). While research has documented an approximate 7% loss in accuracy of assessment results when session duration is reduced from 15 min to 5 min, studies that utilized 5-min duration in FAs increased threefold between 2003 to 2013 to increase efficiency (Beavers et al., 2013). Considering the increased efficiency relative to the minimal reduction in accuracy, as well as the anticipated exposure to loud noise across multiple sessions in this study, 5 min was selected as the session duration to enhance efficiency and reduce the aversiveness of the study sessions.

Two conditions were randomly alternated in the modified FA: (a) silent (low stimulation) and (b) noise (high stimulation). Each session was 5 min in duration. Procedures in the silent condition of the modified FA were identical to the procedures in the screening assessment (steps 1-10 in Table 4), while the procedures in the noise condition of the modified FA included the same procedures plus two additional steps (steps 12-13 in Table 4). These additional steps were placing the speaker out of reach to the participant and presenting intermittent white noise throughout the session. The presentation of noise was independent of the occurrence or nonoccurrence of the target behaviors. In the noise condition, intermittent white noise was presented at 50-60 dB as an auditory stimulus to imitate the noise level in a classroom with ongoing activities, loud voices, and background music (Russo et al., 2018), which was similar to the average volume in a typical classroom with regular activities and talking (Dockrell & Shield, 2006). Presenting sounds at or below 85dB for less than 20 min a day was in adherence with World Health Organization guidelines on safe exposure levels for noise (World Health Organization, 2015). A non-social auditory stimulus (i.e., white noise) instead of social auditory stimuli (e.g., speech, music) was selected to eliminate the potential confound of social variables in the modified FA. Other forms of stimuli, such as visual or tactile, were not used in this study as the delivery of social contingencies might be necessary to ensure that participants attended to visual or tactile stimuli (e.g., "look at this", "play with this").

For Aubrey an additional phase of the modified FA (i.e., with access to toy) was introduced as the clinic staff reported based on informal observations that Aubrey's repetitive behavior tended to occur at a higher frequency when she engaged with preferred toys or items, which were frequently accessible in her natural setting. That is, access to preferred items was a natural contingency that was not present in the FA setting. In this additional phase, the clinic staff presented a preferred toy or item (e.g., glitter slime, princess pictures, stuffed doll) at the beginning of each session and told Aubrey "you can play with this if you want" (steps 13 in Table 4). This phase was designed to simulate a more natural environment for Aubrey during the study sessions.

Table 4. Study Session Procedural Fidelity Checklist

Study Procedures
Steps for SA and all conditions of FA
1. Participant wears a wristband throughout session
2. Participant is video recorded throughout session
3. Staff stays in the same room as participant and maintains distance (approx. 6 ft)
4. Instructional materials are absent or out of reach
5. Toys are absent or out of reach
6. Speech generating device is present, if applicable
7. Staff ignores all mands
8. Staff ignores all target behaviors
9. If participant attempts to take wristband off or reach for other items, staff blocks attempt without providing additional attention
10. Session is ended when duration reaches 5 min or when a termination criterion is met
Additional steps for noise condition of FA
11. Speaker is placed out of reach to participant
12. Intermittent noise is played for 5 min
Additional steps for toy access condition of FA
13. A preferred item/toy is presented at start of session

Note. Each step can be marked as correct, incorrect, or not applicable. SA = screening assessment; FA = functional analysis.

Procedural Fidelity

Procedural fidelity data were collected by two independent observers through evaluating video recordings of study sessions against a researcher-developed checklist for at least 33% of sessions across the screening assessment and each condition of the modified FA. Primary observers included doctoral students in special education and secondary observers included undergraduate research assistants in education or speech and language hearing sciences. A total of 13 items were included in the procedural fidelity checklist. Each step in the checklist could be scored as correct, incorrect, or not applicable. Each step had to be implemented correctly throughout a session to be scored as correct. If a step was implemented incorrectly at any point in time during a session, the step was scored as incorrect. If there was no opportunity to observe a step throughout a session, the step was scored as not applicable. Procedural fidelity was calculated as a percentage score for each session by totaling the number of correct steps, divided by the total number of applicable steps, and multiplying by 100. As shown in Table 5, a mean procedural fidelity score was obtained for the screening assessment and modified FA for each participant.

Table 5. Procedural Fidelity of Study Sessions

	Procedural Fidelity (%)		Procedural Fidelity IOA (%)	
Participant	SA	FA	SA	FA
Cassie	100	99 (88-100)	96 (92-100)	100
Greta	100	98 (88-100)	92	91 (85-92)
Roger	89 (88-89)	100	100	100
Marc	97 (88-100)	100	96 (92-100)	98 (92-100)
Griffin	100	98 (86-100)	100	94 (85-100)
Aubrey	100	100	96 (92-100)	96 (77-100)

Note. IOA = interobserver agreement; SA = screening assessment; FA = functional analysis. Values presented include a mean followed by a range in parentheses.

IOA of the procedural fidelity data was obtained across 50% of the sessions scored by the primary observer and evenly distributed across conditions. A point-by-point agreement method was used to compare the checklists completed by the two observers. Two observers were considered to be in agreement when they scored a step identically (i.e., correct and correct; incorrect and incorrect; not applicable and not applicable). Two observers were considered to be in disagreement when they scored a step differently (i.e., correct and incorrect; correct and not applicable; incorrect and not applicable). IOA data were calculated as a percentage by totaling the number of steps in agreement divided by the total number of steps (i.e., 13 steps), and multiplying by 100. A mean IOA of procedural fidelity was obtained for the screening assessment and modified FA for each participant and shown in Table 5.

Data Analysis

Restricted and Repetitive Behavior

In the screening assessment and the modified FA, the duration of target behavior in each session was plotted on a line graph and analyzed across sessions through visual inspection of the data. For the screening assessment, the level, trend, and variability of data were analyzed to confirm if a participant's target behavior was primarily maintained by automatic reinforcement. For the modified FA, the level, variability, and overlap of data were analyzed across the silent and noise conditions to subtype the automatic function of a participant's target behavior. Comparatively higher levels of target behavior in the silent condition than the noise condition would indicate an automatic positive reinforcement subtype; comparatively higher levels of target behavior in the noise condition than the silent condition would indicate an automatic negative reinforcement subtype; overlapping and undifferentiated levels of target behavior across the two conditions would indicate a mixed automatic reinforcement subtype.

To supplement the visual analysis of behavior data, a single-case effect size was calculated using Nonoverlap of All Pairs (NAP) between conditions within each participant. NAP was selected as an effect size for its sensitivity in discriminating between conditions or phases that are not clearly differentiated and its relatively high reliability with visual judgements (Parker & Vannest, 2009). NAP values ranging between 0 to .65 indicate weak effects or large overlap, .66

to .92 indicate medium effects or overlap, and .93 to 1.0 indicate large effects or small overlap. A web-based effect size calculator was used for the calculation of NAP (Vannest et al., 2016).

Heart Rate Variability

A nonparametric Spearman rank correlation analysis was used to determine the association between levels of RRB and HRV across all sessions among the five participants whose behavioral functions were classified as one of the automatic reinforcement subtypes. Spearman rank was selected over Pearson correlation analysis as the sample consisted of data that were not independent (i.e., repeated measure over time within a participant). A Wilcoxon signed rank test statistic (Wilcoxon, 1945) was used to compare mean HRV between two conditions. Additionally, within-participant mean HRV was extracted and graphed visually to descriptively identify potential differences in HRV changes across the functional subtypes.

CHAPTER 4: RESULTS

Screening Assessment

Results of the screening assessment for all participants are displayed in Figure 2. Visual analysis was used to analyze the screening assessment results to determine if a participant's target behavior was maintained by automatic reinforcement. For Cassie, low to moderate levels of target behavior (*M* = 66, range = 0-139) were observed across six sessions. Despite the relatively low and variable levels across sessions, the target behavior was observed in five out of six sessions and showed no decreasing trend overall, indicating that Cassie's target behavior was likely maintained by automatic reinforcement.

For Greta, low to moderate levels of target behavior (*M* = 133, range = 34-191) were observed across six sessions. In four out of six sessions, Greta engaged in moderate levels of the target behavior with minimal variability. Overall, Greta's screening assessment result indicated that her behavior was most likely maintained by automatic reinforcement.

For Roger, moderate to high levels of target behavior were observed (*M* = 169, range = 106-215), with an increasing trend across five consecutive sessions. These observations suggested that Roger's target behavior was most likely maintained by automatic reinforcement. For Marc, moderate levels of target behavior (*M* = 113, range = 61-169) were observed, with a stable increasing trend over five consecutive sessions. The persistent occurrence and increasing duration of target behavior across sessions suggested that Marc's target behavior was most likely maintained by automatic reinforcement.

For Griffin, high and stable levels of target behavior (*M* = 175, range = 140-212) were observed over five consecutive sessions, indicating that his target behavior was most likely maintained by automatic reinforcement.

For Aubrey, low levels of target behavior (*M* = 62, range = 21-136) with a slight decreasing trend were observed across the first six sessions. However, the behavior did not diminish to zero and showed a large increase in duration from sessions 6 to 8. Overall, Aubrey's result suggested that the behavior was likely maintained by automatic reinforcement.

In summary, the screening assessment results of all six participants suggested that they engaged in repetitive behavior that was primarily maintained by automatic reinforcement. Thus, six participants continued to participate in the next phase of the study, the modified FA, for more specific determination of functional subtype.

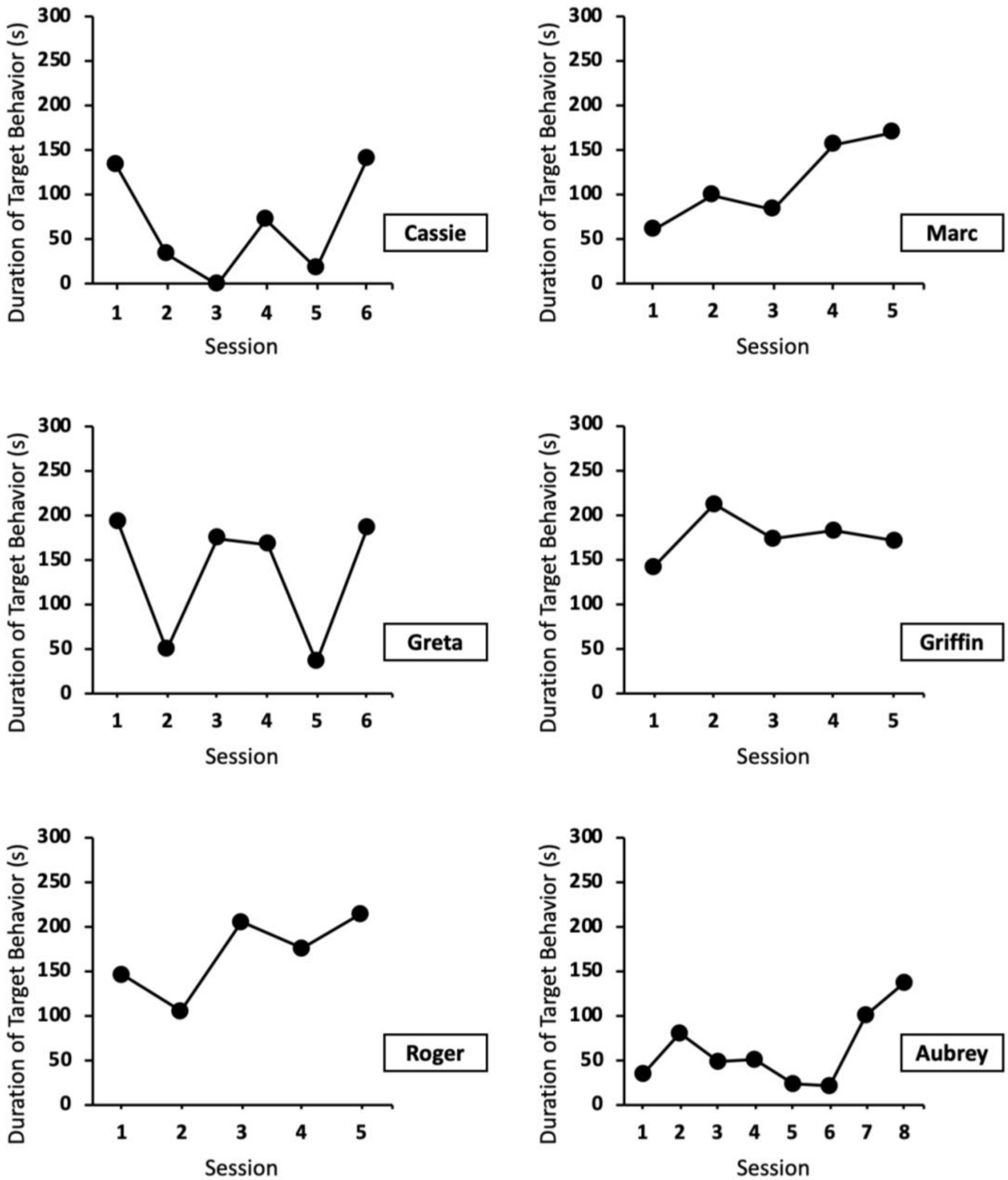

Figure 2. Screening assessment results: the left panel shows the assessment results for Cassie, Greta, and Roger, the right panel shows the assessment results for Marc, Griffin, and Aubrey

Modified Functional Analysis

Automatic Reinforcement Subtypes

Results of the modified FA are displayed in Figure 3. Results of the modified FA were evaluated using visual analysis to determine the specific functional subtype. A nonparametric single-case effect size NAP (Parker & Vannest, 2009) was used to supplement the visual analyses.

For Cassie, the mean duration of her target repetitive behavior was 88 s (range = 26-176) in the silent condition and 40 s (range = 7-125) in the noise condition. She showed moderate levels of target behavior (vocal and motor stereotypy) in the silent condition and low levels of target behavior in the noise condition were initially observed from session 1 to 7, with no overlap between the two conditions. A medication change occurred before session 3 but no observable changes were observed in either condition in the sessions immediately following the medication change. Beginning from session 8, increased variability was observed across both conditions, resulting in substantial overlap and lack of clear differentiation in the duration of target behavior. However, over the last six sessions (sessions 19 to 24) of the modified FA, Cassie demonstrated low and stable levels of target behavior in the noise condition and moderate and stable levels of target behavior in the silent condition. While staff changes occurred frequently over sessions 17 and 24, these changes did not appear to visibly influence Cassie's levels of target behavior. NAP effect across the two conditions was 0.826, indicating medium overlap. Overall, Cassie's result indicated that the function of her target behavior was automatic positive reinforcement.

For Greta, levels of the target repetitive behavior (vocal stereotypy) were relatively low and stable (M = 58, range = 23-109) in the noise condition, while levels in the silent condition were moderate with some variability (M = 130, range = 47-215). A clear differentiation with minimal overlap in levels of target behavior between the silent and noise conditions was observed, with relatively higher levels of target behavior in the silent condition than in the noise condition. NAP effect across the two conditions was 0.889, indicating medium overlap. The modified FA result over 17 sessions suggested that the function of Greta's target behavior was automatic positive reinforcement.

For Roger, moderate to high levels of target behavior (vocal and motor stereotypy) were observed in the silent condition (M = 102, range = 33-199) and the noise condition (M = 71, range = 0-232) within the first five sessions of the modified FA. A one-month break occurred between sessions 5 and 6 when Roger did not receive services at the autism clinic due to a decrease in treatment service capacity within the clinic. Roger resumed study participation after he returned to the clinic for treatment. Upon his return, a change in staff occurred and the study session time changed from 10:00 a.m. to 1:00 p.m. After his return from the break, large decreases in the target behavior were observed across both silent (*M* = 62, range = 33-76) and noise (*M* = 20, range = 0-48) conditions. While the levels of his target behavior were generally low in both conditions between sessions 6 to 14, relatively higher levels of target behavior were observed in the silent condition than in the noise condition, with a clear separation of data between the two conditions. NAP effect across the two conditions was 0.694 across all 14 sessions of the modified FA, indicating medium overlap. Roger's result indicated that the function of his target repetitive behavior was automatic positive reinforcement.

For Marc, the levels of his target repetitive behavior (vocal stereotypy) were moderate and stable (*M* = 119, range = 90-140) in the silent condition, while levels in the noise condition were higher with slightly more variability (*M* = 155, range = 114-190). An overlap in levels across the two conditions was observed over sessions 5 and 6. However, a clear differentiation in the levels of target behavior was demonstrated between the two conditions across most of the sessions. NAP effect was 0.760 across the two conditions, indicating medium overlap. Marc's modified FA result suggested that the function of his target repetitive behavior was automatic negative reinforcement.

For Griffin, the levels of his target behavior (vocal stereotypy) ranged from moderate to high in both silent (*M* = 173, range = 124-229) and noise (*M* = 149, range = 84-202) conditions. The variability of data was large in both conditions, with no clear trend across 18 sessions. In addition, a substantial overlap in levels was observed between the two conditions. NAP effect was 0.667 across the two conditions, indicating a medium effect. As no visible differentiation in levels was observed and no predictive patterns emerged while levels remained relatively high in both conditions, Griffin's modified FA result suggested that the function of his target behavior was mixed automatic reinforcement (i.e., both automatic positive and automatic negative reinforcement).

For Aubrey, during the first six sessions, low levels of target behavior (vocal and motor stereotypy) were observed across both silent and noise conditions. In subsequent sessions, diminishing and near zero levels of the target behavior were observed in both the noise and silent conditions. A change of room occurred beginning from session 10 after the clinic staff who worked with Aubrey reported that Aubrey refused to enter the initial room used for implementing study sessions, for reasons that were not identified. The change of location did not influence her levels of target behavior in the subsequent study sessions. Up to session 14, the mean duration of target behavior in the silent condition was 16 s (range = 0-72) and 6 s in the noise condition (range = 0-44). Beginning from session 15, access to a preferred toy or item was introduced. However, observations across six sessions (session 15 to 21) showed no increase in the levels of target behavior in both conditions with a mean duration of 1 s (range = 0-4) in the silent condition and a mean duration of 3 s (range = 0-5) in the noise condition. Across all sessions of the modified FA (session 1 to 21), NAP effect was 0.355 between the two conditions, indicating large overlap. Taken together, Aubrey's modified FA result indicated that the function of her target repetitive behavior was social reinforcement instead of automatic reinforcement.

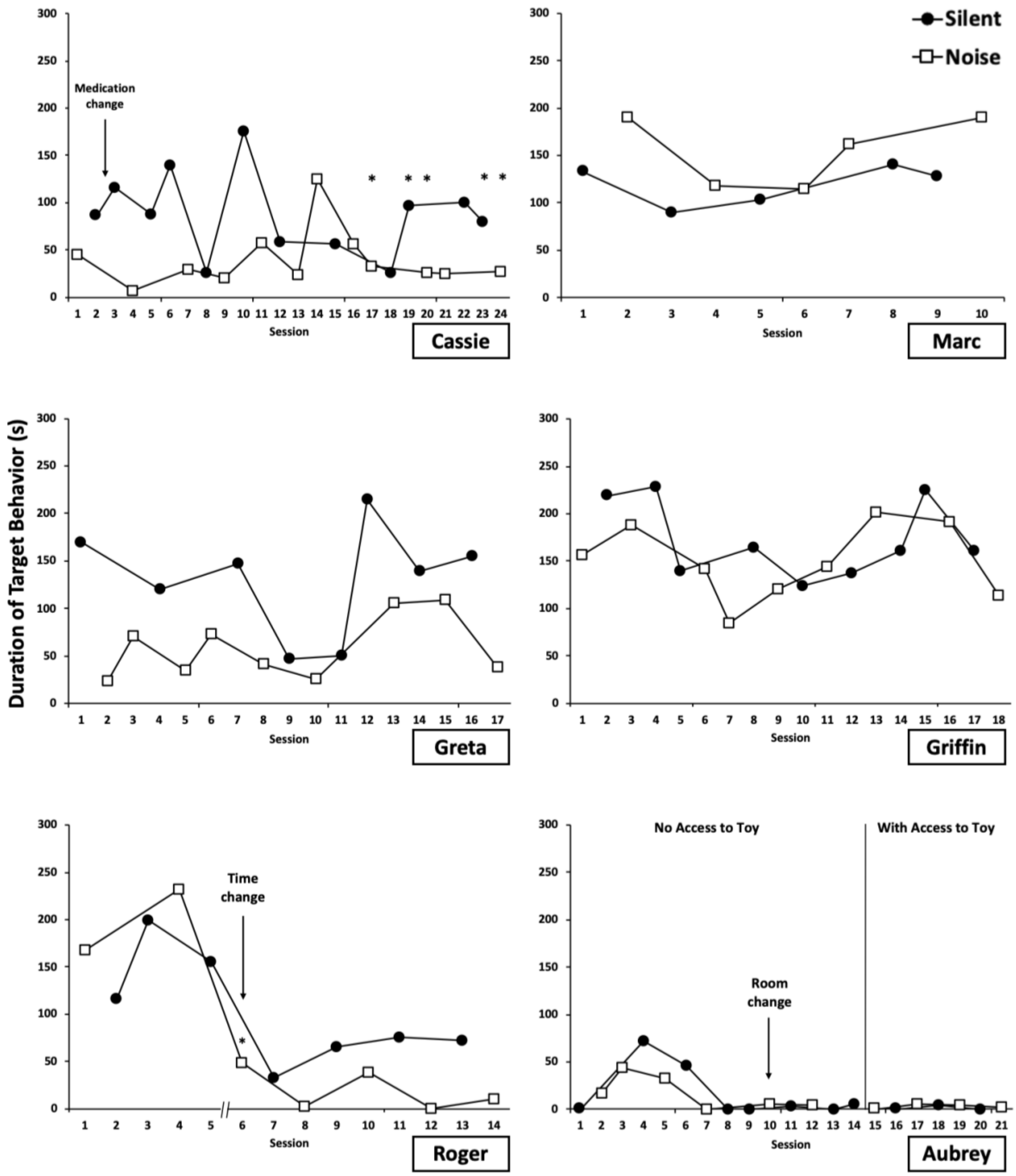

Figure 3. Results of the modified functional analysis for six participants. Asterisks (*) indicate sessions with a change in staff who implemented the session. For Cassie, a medication change occurred before session 3 and staff changes occurred in sessions 17, 19, 20, 23, and 24. For Roger, a one-month break occurred between sessions 5 and 6, a staff change occurred in session 6, and a time change (from morning to afternoon) occurred beginning from session 6. For Aubrey, study sessions were implemented in a different clinic room beginning from session 10.

Heart Rate Variability and Restricted and Repetitive Behavior

A total of 83 modified FA sessions were implemented with five participants whose behavioral function was classified as automatic reinforcement (Cassie, Greta, Roger, Marc, and Griffin). Aubrey was excluded from the correlational analysis between HRV and RRB as her behavioral function was shown to be maintained by social reinforcement. Out of 83 modified FA sessions across the five participants, HRV data from 80 sessions (96%) were used to determine the correlation between the primary and secondary dependent variables, duration of RRB and HRV. Three study sessions were excluded from the HRV analysis as HRV data were unavailable due to manual errors in the use of the digital wristband. A significant positive correlation was found between HRV and duration of repetitive behavior, $r(79) = .552$, $p < .001$. The scatterplot of the correlation analysis is displayed in Figure 4, with different shapes of data points representing the three automatic reinforcement subtypes respectively.

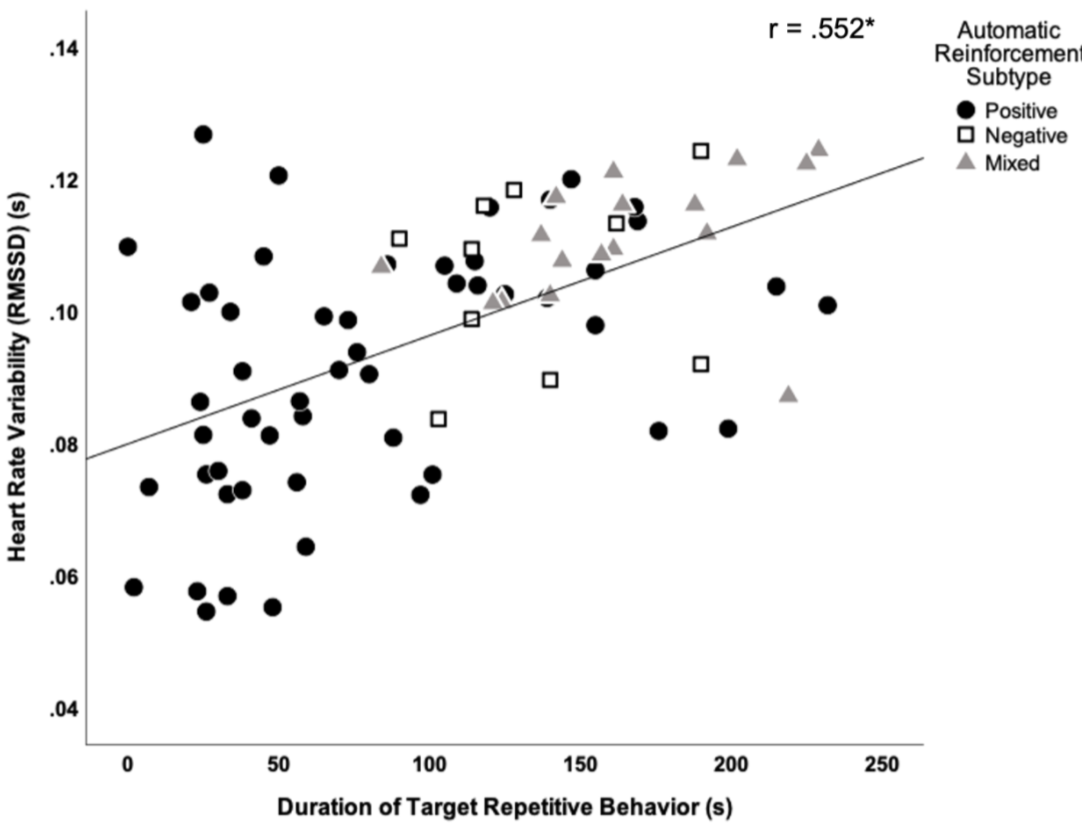

Figure 4. Scatterplot of correlation of heart rate variability (RMSSD/s) and repetitive behavior across modified functional analysis sessions of five participants (Cassie, Greta, Roger, Marc and Griffin); $r = .552$; * $p < .001$; data points were categorized based on automatic reinforcement subtypes including positive, negative, and mixed

Mean HRV aggregated across participants was 0.0993 (SD = 0.010) in the silent condition and 0.0976 (SD = 0.013) in the noise condition and displayed in Figure 5. A Wilcoxon rank sum test (Wilcoxon, 1945) revealed no significant difference in HRV between conditions (p = 0.81). Mean HRV data disaggregated by participant and classified by subtype are shown in Figure 6. Preliminary HRV changes across subtypes can be observed, with reduced HRV from the silent to noise condition observed for the automatic positive reinforcement subtype, increased HRV for the automatic negative reinforcement subtype, and no change in HRV for the mixed automatic reinforcement subtype.

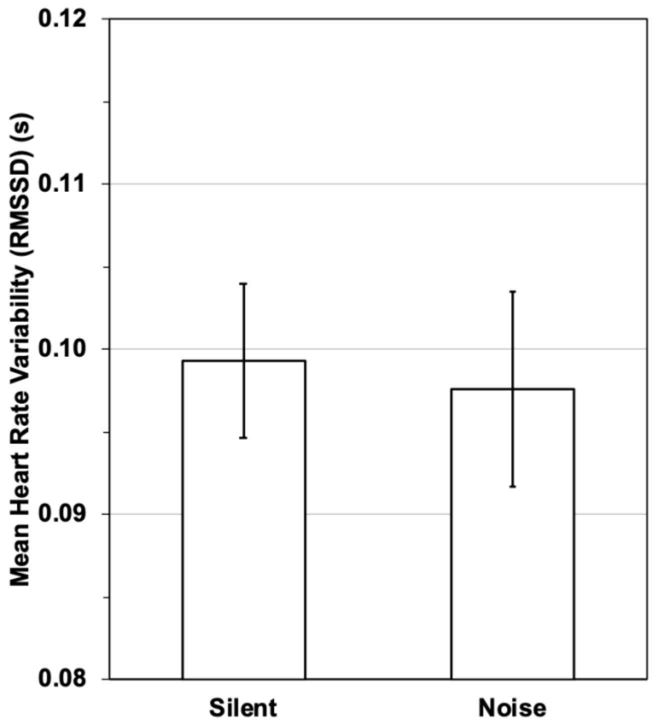

Figure 5. Comparison of mean heart rate variability aggregated across five participants (Cassie, Greta, Roger, Marc, Griffin) between conditions, with standard error of mean

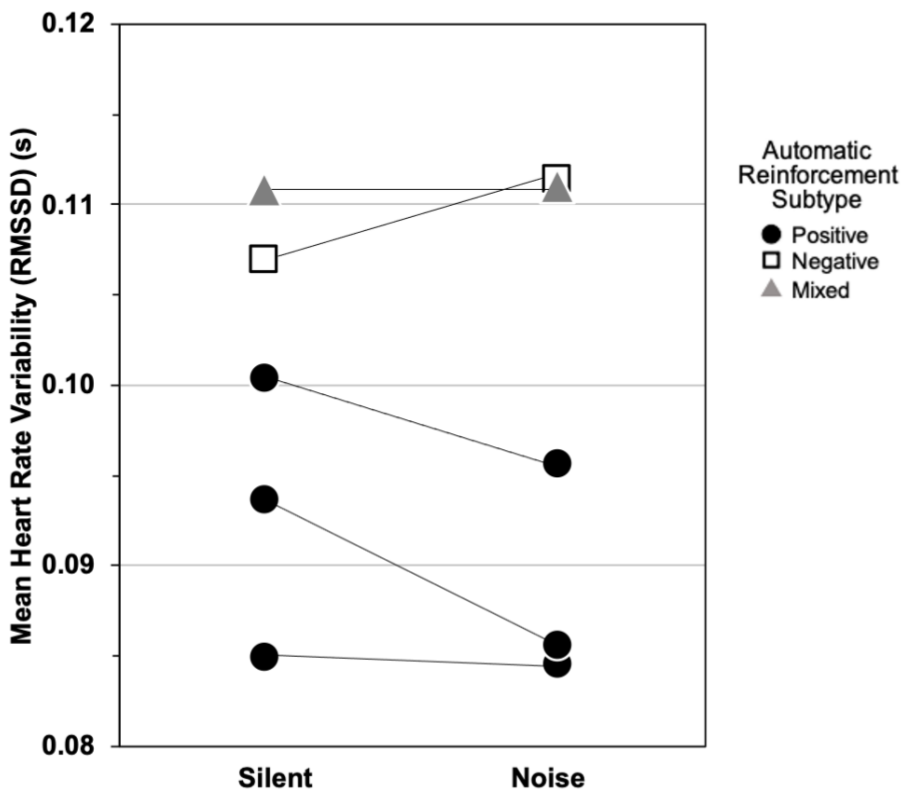

Figure 6. Comparison of mean heart rate variability aggregated across sessions for each of five participants (Cassie, Greta, Roger, Marc, Griffin) between conditions

CHAPTER 5: DISCUSSION

The current study aimed to identify potential subtypes of automatic reinforcement and determine if automatically maintained vocal or motor repetitive behavior in individuals with ASD is associated with autonomic arousal, as indexed by HRV. A modified FA consisting of alternating silent (low-stimulation) and noise (high-stimulation) conditions was conducted across six participants with ASD. Data on both repetitive behavior and HRV were collected in the modified FA sessions. This single-case design experiment aimed to address the following questions:

(a) Can RRB maintained by automatic reinforcement be delineated into automatic positive and automatic negative reinforcement through a modified FA?

(b) Are observable behavior patterns of RRB in the modified FA associated with HRV, an index of autonomic arousal, in individuals with ASD?

It was hypothesized that the modified FA may result in the identification of three subtypes of automatic reinforcement, including automatic positive reinforcement, automatic negative reinforcement, and mixed automatic reinforcement. In this study, if participants engaged in higher levels of RRB in the silent (low stimulation) condition, their behavior was hypothesized to increase access to stimulation and the function of their RRB was classified as automatic positive reinforcement. If participants engaged in higher levels of RRB in the noise (high stimulation) condition, their behavior was hypothesized to decrease access to stimulation and the function of their RRB was classified as automatic negative reinforcement. If participants engaged in undifferentiated levels of RRB across both silent and noise conditions, their behavior was hypothesized to both increase and decrease access to stimulation and the function of their RRB was classified as mixed automatic reinforcement. In relation to the second research question, it was hypothesized that levels of HRV would be associated with the levels of RRB. Results of this study indicated that automatic reinforcement could be further delineated into three subtypes and levels of HRV were associated with levels of RRB. In the following section of this chapter, major findings and interpretations, implications for research and practice, limitations, and future directions are discussed.

Automatic Reinforcement Subtypes

Based on the results of the modified FA, five out of six participants (Cassie, Greta, Roger, Marc, and Griffin) were identified to have RRB maintained by automatic reinforcement, while one participant (Aubrey) was identified to have RRB maintained by social reinforcement. Among the five participants whose RRB was determined to be automatically maintained, three participants (Cassie, Greta, and Roger) demonstrated behavior patterns that indicated a behavioral function of automatic positive reinforcement; one participant (Marc) demonstrated behavior patterns that indicated a behavior function of automatic negative reinforcement; one participant (Griffin) demonstrated behavior patterns that indicated a behavior function of mixed automatic reinforcement.

Automatic Positive Reinforcement

The silent condition of the modified FA was designed based on the ignore condition described by Iwata and colleagues (1982/1994), which simulates a relatively bare environment with no social contingencies and minimal environmental stimulation. The deprived state created an establishing operation for the engagement of behavior maintained by access to stimulation. Conversely, when noncontingent auditory stimulation was provided in the noise condition, it provided an external source of stimulation that was not associated with social contingencies and created an abolishing operation for the engagement of behavior maintained by access to auditory stimulation (Laraway et al., 2003; Michael, 1993). Therefore, when three participants (Cassie, Greta, and Roger) engaged in more RRB in the silent condition compared to the noise condition, it was deduced that their behavior produced automatic positive reinforcement.

This finding aligns with prior studies that demonstrated the effects of noncontingent auditory stimulus intervention (e.g., music, dialogue extracts from preferred TV shows or films, audio recordings of vocal stereotypy) on RRB maintained by automatic reinforcement (Cook & Rapp, 2020; Gibney et al., 2020; Lanovaz et al., 2014; Lanovaz & Sladeczek, 2011; Love et al., 2012; Rapp et al., 2013). While the modified FA in the current study was designed to assess the function of the target behavior, the alternating treatments design used for the assessment allowed for the evaluation of effects of the presence and absence of noncontingent auditory stimulation on the duration of RRB displayed by each participant. For these three participants, levels of the RRB were substantially lower in the presence of auditory stimulation than in its absence. This unintended therapeutic change in RRB may suggest that the noncontingent delivery of background noise provided a competing source of stimulation that resulted in a decrease of the behavior.

It is worth noting Roger's overall levels of RRB changed drastically across both conditions after his return from a one-month break. Upon his return, a change in clinic staff occurred and his study session time was changed from morning to afternoon. While it was not possible to identify a specific factor that led to the change in overall levels of RRB, it is possible that habituation occurred over time when Roger's RRB was repeatedly exposed to the study conditions. However, it was beyond the scope of this study to further examine this change.

Automatic Negative Reinforcement

In addition to identifying behavior maintained by automatic positive reinforcement, the modified FA was also designed to identify behavior maintained by automatic negative reinforcement. The high-stimulation environment presented in the noise condition likely created an establishing operation for the occurrence of behavior maintained by escape from stimulation, while the low-stimulation environment presented in the silent condition created an abolishing operation for the occurrence of behavior maintained by escape from stimulation. Therefore, for the participant (Marc) whose RRB was higher in the noise condition compared to the silent condition, the behavior was likely maintained by automatic negative reinforcement. In other words, engaging in RRB automatically removed or reduced access to stimulation.

This finding aligns with prior research that conceptualized automatic negative reinforcement as a potential functional subtype of the automatic reinforcement function (Rapp & Vollmer, 2005; Vollmer, 1994). It also aligns, in part, with a prior study conducted by Tang and colleagues (2002), who found that the addition and removal of noise contingent on each occurrence of a child's stereotypic behavior within an analogue FA resulted in differential levels of stereotypic behavior. Tang et al. (2002) suggested that automatic negative reinforcement was a potential function of the target stereotypic behavior because the child's stereotypy increased in the condition when noise was removed as a consequence of the behavior (Tang et al., 2002). However, social contingencies could not be ruled out in the FA in Tang et al. (2002) as the noise was turned off by another person contingent on the participant's ear covering behavior, which constituted social negative reinforcement (escape from noise through the mediation of another individual). In the current study, the modified FA did not include the delivery of social positive reinforcement or social negative reinforcement, and thus, automatic negative reinforcement was the most probable classification of function based on Marc's assessment results.

Mixed Automatic Reinforcement

While differentiated levels across the silent and noise conditions of the modified FA indicated either automatic positive or automatic negative reinforcement, undifferentiated levels and persistent occurrences of RRB in both conditions suggested the behavior served both automatic positive and automatic negative reinforcement functions. This may suggest that Griffin engaged in moderate to high levels of RRB in the silent condition to access stimulation that was not accessible in the environment. Likewise, he engaged in similar levels of RRB in the noise condition to escape from or reduce the stimulation he accessed in the environment. Therefore, his RRB was determined to have a combination of automatic positive and automatic negative reinforcement function—mixed automatic reinforcement. This finding aligns with some literature that suggests the possibility of a behavior producing both positive and negative reinforcement without the mediation of another person, such as scratching, which may produce both sensory stimulation on the skin and the removal of physical pain or discomfort (Cataldo & Harris, 1982; Iwata, Pace, et al., 1994).

The use of the term "mixed automatic reinforcement" was intended to refer to a different subtype of the broader "automatic reinforcement" function rather than its equivalent. Typically the automatic reinforcement function can be deduced if a behavior persists in the absence of any social contingencies, while the social reinforcement function can be deduced if a behavior occurs minimally or does not occur in the absence of social contingencies (Hanley et al., 2003; Iwata et al., 1982/1994; Schlichenmeyer et al., 2013). This logic implies that such a functional analysis methodology (i.e., using an alone or ignore condition to detect the probability of automatic reinforcement) allows for the conclusion of automatic reinforcement only when social contingencies are ruled out without identifying the specific automatic contingencies. In such cases, the term "automatic reinforcement" should be taken to mean nonsocial reinforcement rather than a mixture of both automatic positive and automatic negative reinforcement, as these subfunctions have not been verified. In the current study, Griffin's RRB was detected at moderate to high levels in both the silent and noise conditions, indicating that the behavior persisted across settings that varied in levels of nonsocial environmental stimulation. Hence, it is more likely that Griffin engaged in RRB to both access and escape stimulation depending the level of environmental stimulation he accessed, which led to the conclusion that his RRB was maintained by mixed automatic reinforcement.

Social Reinforcement

When the levels of RRB were compared across the silent and noise conditions, conclusions about automatic reinforcement subtypes could be formed based on visual analyses of the level, trend, variability, and overlap of data between the two conditions. However, RRB must have occurred in either condition for the subtype conclusions to be drawn. In one participant's case, RRB occurred at near zero levels in both conditions throughout the modified FA. Prior research suggests that when automatically maintained behavior is displayed at minimal levels in the alone or ignore condition of an FA, it could potentially be attributed to the lack of similarity between the FA setting and the participant's natural environment. To better capture the contingencies that are present in the natural setting where the target behavior typically occurs, relevant stimuli that are present in the natural setting can be incorporated into the FA setting to simulate a more natural environment (Carter et al., 2004; Tiger et al., 2006). In the current study, when Aubrey's RRB was barely detectable in both conditions for several consecutive sessions, it was hypothesized that the FA setting might not have captured critical and relevant stimuli that were typically present in her natural settings, such as having free access preferred items or toys. Hence, an additional phase of the modified FA with access to a preferred toy or item was introduced with the purpose of capturing a potentially relevant establishing operation for her RRB. However, contrary to the hypothesis, Aubrey's RRB did not increase in either condition in the additional phase. When the screening assessment and modified FA were implemented, the occurrence of RRB did not produce any socially mediated changes in the environment. In essence, extinction was implemented for any behavior that was maintained by social reinforcement. Therefore, based on the near zero levels of RRB displayed over consecutive sessions of both the silent and noise conditions, it was concluded Aubrey's RRB did not have a primary function of automatic reinforcement and that her screening assessment likely produced a false positive result. However, while it was probable that her RRB had a social reinforcement function based on the observations in the modified FA, a definite conclusion about social reinforcement could not be drawn unless a more comprehensive FA was implemented.

The screening assessment in this study was adapted from the protocol developed by Querim et al. (2013) and was intended to efficiently determine if automatic reinforcement was the most probable function of a behavior. In the current study, the average time used to complete the screening assessment across six participants was 29 min (range = 25-40 min), which was approximately 34% of the time used for completing the modified FA across two conditions (M = 29 min, range = 50-120 min). The relative efficiency aligns with the enhanced efficiency reported by Querim and colleagues (2012), who concluded that the time needed to identify an automatic reinforcement function through a screening assessment was approximately 13% of the time needed to determine an automatic reinforcement function through a full FA across four or more conditions. However, it was also noted that the enhanced efficiency may inflict a cost on the accuracy of results (Querim et al., 2013). In their analyses across a sample of 30 participants with intellectual and developmental disabilities between the ages 9 to 47 years old, it was found that the predictions of behavior function based on results of the screening assessment corresponded with results from a full FA 93% of the time. Similarly, in the current study, the screening assessment and FA results did not show complete correspondence, with five out of six participants (83%) showing agreeable results between the two assessments on the identification of automatic reinforcement as a primary function.

Heart Rate Variability and Restricted and Repetitive Behavior

Across five participants whose behavior function was classified as automatic reinforcement, a significant positive correlation was found between HRV and duration of RRB across the modified FA sessions. In these sessions, the level of environmental stimulation was manipulated across the silent and noise conditions, resulting in differential levels of RRB. Overall, when participants engaged in lower levels of RRB, their HRV was lower. Conversely, when participants engaged in higher levels of RRB, their HRV was higher. While this finding is preliminary and based on a small sample, it confirmed the hypothesis that the external display of automatically reinforced RRB is associated with internal neurophysiological responses in children with ASD.

Prior research has established that HRV is a fairly direct indicator of ANS activity (Friedman, 2007; Wass et al., 2015) and higher HRV tends to indicate more typical regulation of autonomic arousal, which influences an individual's behavior in response to the environment (Porges, 2007). Furthermore, a number of studies have demonstrated that individuals with ASD tend to have reduced HRV compared to typically developing individuals (Guy et al., 2014; Lory et al., 2020; Neuhaus et al., 2014; Thapa et al., 2019, 2020). Taken together with the findings of this study, it can be posited that individuals with ASD engage in RRB to increase HRV to levels that represent more neurotypical regulation of the ANS, in response to an environment that either presents too much or too little stimulation.

When a comparison of HRV aggregated across participants was made between the two FA conditions implemented in this study, the participants did not show a significant difference in HRV. This may suggest that HRV is likely less associated with the absolute level of stimulation in the environment (i.e., low stimulation in the silent condition and high stimulation in the noise condition) but rather more directly associated with the occurrence of RRB. This implies that individuals with ASD may have unique upper and lower thresholds for environmental stimulation that allow them to remain at rest, without engaging in RRB. An environment that presents stimulation at a level that exceeds the upper threshold or falls below the lower threshold of an individual with ASD may result atypical activity of the ANS, resulting in the increased duration of RRB as well as increased levels of HRV. In addition, when mean HRV was disaggregated by participant and categorized by subtype, a preliminary trend in mean HRV could be observed within each participant and subtype. It was found that compared to HRV in the silent condition, the noise condition increased, decreased, or maintained the HRV of a participant whose RRB was classified as the positive, negative, or mixed subtype respectively. To some extent, this finding aligns with prior research that suggests individuals with ASD may consist of subgroups that can be classified as hyper- or hypo-reactive to sensory stimulation (Boyd et al., 2010; Liss et al., 2006).

It may be of interest to note that the positive correlation between HRV and RRB found in this study may appear to misalign with some prior studies that found a negative correlation between HRV and more atypical reactivity to sensory stimulation in the environment (Lory et al., 2020) and severity of RRB (Thapa et al., 2020) in children with ASD. However, findings should be interpreted in the context of the measures used in each study to draw more specific conclusions on the relationship between autonomic arousal and external behavior. In the prior studies, measures of behavior involved indirect estimates of the frequency and severity of behavior, such as the Child Sensory Profile, Second Edition (Dunn, 2014). The external behavioral symptoms of ASD measured using these standardized assessments may or may not occur within the same window of time when HRV is measured. In the current study, RRB was measured based on direct observations of the behavior at the same time when HRV was measured. Therefore, the HRV changes across sessions within each participant in this study may be more representative of the participants' autonomic arousal across situations in their natural environment and more sensitive to the variation in levels of RRB within an individual.

Implications for Research

This study offers preliminary evidence that a modified FA adapted from the protocol of the ignore or alone condition in the analogue FA model developed by (Iwata et al., 1982/1994) can potentially be effective in delineating subtypes of automatic reinforcement, including (a) positive, (b) negative, and (c) mixed. The identification of automatic reinforcement subtypes aligns with the conceptualization of reinforcement as a contingency that may involve both the addition and removal of stimulus (Cooper et al., 2020) and literature that suggests the existence of both positive and negative reinforcement within the category of automatic reinforcement (Rapp & Vollmer, 2005; Vollmer, 1994). Furthermore, as prior research on delineating subtypes of automatic reinforcement has focused primarily on self-injurious behavior (Hagopian et al., 2015, 2017), this study makes additional contribution to the literature by expanding the examination of functional subtypes to a sample of individuals with ASD who engaged in other topographies of RRB, such as out-of-context vocalizations and repeated body or limb movements that did not involve physical harm towards self or others.

While some research has emerged to examine both the external display of challenging behavior and the internal physiological responses among individuals with developmental disabilities (Jennett et al., 2011; Lydon et al., 2013, 2015), no studies to date have examined the relationship between HRV and RRB through simultaneous and direct measures of both variables utilizing an FA model of assessment. In this study, the simultaneous collection of RRB data through direct observations and HRV data through wearable technology was a novel method in integrating direct measures of behavior and autonomic arousal. The significant association between levels of HRV and RRB found in this study suggests that the frequency of RRB observed in children with ASD may be an indication of autonomic regulatory activity in response to sensory stimulation changes in the environment. This may offer an opportunity for researchers to more closely examine the usefulness and advantages of using direct observational measures RRB compared to indirect measures of RRB in children with ASD. For instance, it may be worth exploring under what condition and to what extent the usefulness of the data in identifying specific environmental contexts and variables that tend to evoke a behavior may offset the time and personnel resources required to implement more direct measures of the behavior. Further investigations with a more comprehensive cost-benefit analysis would be warranted.

In addition, this study also included young children with ASD with relatively frequent and directly observable RRB (e.g., out-of-context vocalizations, repeated motor movements) and low adaptive skills. This is in contrast with majority of the research that examined HRV in individuals with ASD in that prior studies typically recruited participants with ASD whose intellectual or cognitive and adaptive abilities were comparable to neurotypical peers (Cheng et al., 2020). Considering the heterogeneity of cognitive and adaptive abilities among individuals with ASD, with a majority proportion (over 50%) of the population receiving a diagnosis of mild to severe intellectual disability (Chiarotti & Venerosi, 2020), this study adds to the literature by including an underrepresented sample of children with ASD as participants in a study that measured their neurophysiological features.

Implications for Practice

As noted in the interpretations of study findings, the modified FA implemented in this study was not purposefully designed to serve as a treatment for reducing RRB in children with ASD. However, an unintended therapeutic change in the reduction of RRB in the noise condition across three of the participants suggests that presenting auditory stimulation may be a potentially effectively treatment option for participants whose RRB has been identified to have a function of automatic positive reinforcement. Moreover, it is worth noting that the topography of RRB varied across these participants and was not limited to vocal stereotypic behavior, as two of the three participants (Cassie and Roger) engaged in RRB that consisted of both vocal and motor stereotypies. The consistent reduction across both vocal and motor forms of RRB in the noise condition aligns with prior research that demonstrated the effects of noncontingent access to competing stimuli that may or may not match the mode of sensory stimulation produced by the target behavior, such as chair, wax sticks, slime, tablet, text to speech device, musical books, on the reduction of multiple forms of RRB (Hagopian & Toole, 2009; Rapp et al., 2017).

Additionally, the current study also points to the potential feasibility of coaching practitioners via a telehealth model (i.e., providing live coaching through video conferencing tools) to implement a screening assessment and a modified FA consisting of silent and noise conditions to determine automatic reinforcement subtypes of RRB. A substantial body of research has demonstrated that telehealth can be an effective service delivery model for supporting practitioners or caregivers to implement FAs with children with ASD in applied settings (Machalicek et al., 2009; Machalicek et al., 2016; Schieltz & Wacker, 2020; Wacker et al., 2013). A telehealth approach to the assessment of challenging behavior may reduce geographical barriers and increase access to effective implementation of FAs and function-based interventions for individuals with ASD (Lindgren et al., 2016). In this study, the fidelity of study procedures was relatively high across all clinic staff, demonstrating the potential effectiveness of using telehealth to support practitioners in implementing a modified FA that involved the use of multiple technology devices (i.e., digital wristband, speaker, tablet, video camera). However, it should be noted that data recording and analyses were conducted by a researcher and the clinic staff who implemented the study sessions had prior training in implementing other behavior analytic practices.

Limitations and Future Directions

There are several limitations of this study that should be considered when interpreting the findings. First, auditory stimulation was the only variable that was systematically manipulated across the two conditions of the modified FA. It is possible that the alternating presence and absence of white noise alone may not be the only variable that influences the occurrence of RRB. Thus, overlapping levels of RRB between the two conditions (i.e., in the case of Griffin) might have indicated an inconclusive finding rather than a mixed automatic reinforcement subtype. To determine if automatically maintained RRB may be sensitive to a wider array of environmental stimulation other than auditory stimulation, future research should consider incorporating other types of stimulation (e.g., visual, tactile) that may be presented without involving the delivery of social stimuli and contingencies.

Second, an absence of baseline or resting condition prior to each study session did not allow for the examination of whether HRV levels increased or decreased differently from each participant’s initial state to the silent and noise condition respectively. To determine HRV reactivity in the context of different levels of environmental stimulation, future research should consider collecting baseline HRV data immediately prior to each study condition where the independent variable is manipulated.

Third, the researcher monitored all study sessions via a video conferencing tool, which created a barrier to the verification of whether the wristband fit tightly on each participant's wrist at the beginning of each session. Further, as the design of the modified FA required the clinic staff to withhold social attention from the participant, behaviors that might have produced artifact in the HRV data (e.g., rapidly clapping hands, knocking the wrist on a table or wall) were not stopped. These factors might have contributed to the artifact found in the HRV data. Further exploration of appropriate technology to collect physiological data with young children with ASD who engage in frequent RRB is warranted.

Fourth, this study included a small sample of participants with a primary focus of examining within-participant changes in RRB and HRV. While the study provides some preliminary evidence for (a) the utilization of a modified FA to delineate automatic reinforcement subtypes and (b) explaining the underlying neurophysiological mechanisms that interact with the occurrence of RRB in children with ASD, replication of study findings with a wider population is necessary to make more definite conclusions.

CHAPTER 6: CONCLUSION

With continued and burgeoning interests in identifying the etiology of RRB in individuals with ASD, autism researchers have explored numerous ways to identify the functional properties of RRB and their underlying neurophysiological characteristics. Researchers in behavior analysis have suggested that more specific automatic reinforcement subtypes may exist (Hagopian et al., 2015, 2017; Rapp & Vollmer, 2005; Vollmer, 1994). Yet, despite the continued improvisation of FA models to assess the function of behavior (e.g., Trial-based Functional Analysis; Bloom et al., 2011; Sigafoos & Saggers, 1995; Interview-informed synthesized contingency analysis; Hanley et al., 2014; Hanley, 2012) after the original development of the analogue FA model (Iwata et al., 1982/1994), no established FA models have been developed to identify automatic positive reinforcement versus automatic negative reinforcement as specific functions of behavior. This study investigated the effects of a modified FA model consisting of two conditions that each simulated a high-stimulation and a low-stimulation environment on the identification of more specific automatic reinforcement subtypes. The preliminary findings in the effective identification of three automatic reinforcement subtypes including positive, negative, and mixed, suggest RRB may be maintained by these different subtypes and it is possible to delineate the subtypes using a modified FA.

In parallel, researchers who study ASD from a neurophysiological perspective have invested efforts in developing measures that index ANS modulation in individuals with ASD. Presently, some conclusions have been formed regarding the interaction between autonomic arousal and a continuum of frequency and severity of behavioral features that characterize ASD (Anderson & Colombo, 2009; Benevides & Lane, 2015; Condy et al., 2017; Mathersul et al., 2013; Porges, 2003, 2007; Thapa et al., 2020). However, prior studies that measured autonomic arousal in individuals with ASD often used indirect measures of RRB, such as caregiver-report or practitioner-report questionnaires, when analyzing the relationship between RRB and measures of autonomic arousal, such as HRV (Bujnakova et al., 2016; Muscatello et al., 2021; Schoen et al., 2009). The current study provides a potential model for taking direct and simultaneous measures of RRB and HRV to better capture the immediate interaction between RRB and HRV.

Additionally, most of the prior studies collected HRV measures with participants in highly controlled laboratory settings. A novel feature of this study includes the examination of the potential effect and feasibility of a practitioner-implemented FA that included the use of a wearable device to collect both real-time RRB and HRV data in the participants' natural settings. Study results, as well as measures of procedural fidelity, suggest that the assessment protocol was effective and feasible.

The primary objective of this study aligns with recent calls for exploring interdisciplinary methods to address both biological and environmental factors that influence challenging behavior (Cascio et al., 2016; Kennedy, 2021). This study demonstrated how an integrated assessment using both behavioral and physiological measures may enhance the assessment of RRB and offer new insights on specific variables that influence the occurrence of RRB in the context of ASD. The integrated approach used in this study to assess both functional and neurophysiological features of RRB may guide future research in interdisciplinary assessment to better identify more specific functions and underlying neurophysiological mechanisms that underlie the occurrence of RRB in individuals with ASD.

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