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Variation in Restricted and Repetitive Behaviors and Interests Relates to Inhibitory Control and Shifting in Children with Autism Spectrum Disorder

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Abstract

Symptoms of restricted and repetitive behaviors and interests (RRBIs) in autism are theoretically linked to executive functioning, which includes problem-solving abilities such as inhibition and cognitive flexibility. This study examined whether inhibition and flexibility are related to higher order RRBIs (e.g., circumscribed interests and ritualistic behavior) and sensorimotor behaviors (e.g., stereotyped and repetitive movements and sensory preoccupations) among 102 school-aged children with autism spectrum disorder who had cognitive abilities in the average or above average range. The ability to inhibit interfering information and shifting ability were related to higher order RRBIs, and each uniquely accounted for variance. This suggests that the ability to suppress interfering information as well as the ability to flexibly shift between patterns of responding are protective against higher order RRBI symptoms in autism. In addition, the ability to inhibit rapid responses to work more carefully related to sensorimotor RRBs. These results support the importance of distinguishing between higher order and sensorimotor symptoms due to their distinct relationships to executive functioning abilities.

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by symptoms in social communication and restricted and repetitive behaviors and interests (RRBIs) (American Psychiatric Association, 2013). These core symptoms impact functioning across personal, social, and occupational contexts, and typically persist across the lifespan (Bieleninik et al., 2017; Marriage et al., 2009). The broad symptom category of RRBIs can be subdivided into two correlated yet qualitatively different categories: Insistence on Sameness (IS) and Repetitive Sensory Motor (RSM) behaviors (Bishop et al., 2013; Georgiades et al, 2010; Honey et al., 2012; Turner, 1999) and conceptualized as *higher order*, including preoccupations/circumscribed interests, compulsive routines, and ritualistic behavior, and *sensorimotor*, including stereotyped and repetitive movements and sensory

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preoccupations (Mosconi et al., 2009; Turner, 1999). Following the methods used by Mosconi and colleagues (2009) and Hollander and colleagues (2005), the Autism Diagnostic Interview-Revised (ADI-R) algorithm items C1 (encompassing preoccupations or circumscribed patterns of interest) and C2 (apparently compulsive adherence to nonfunctional routines or rituals) comprised a "higher order" repetitive behavior category, whereas items C3 (stereotyped and repetitive motor mannerisms) and C4 (preoccupations with parts of objects or non-functional elements of materials) comprised a "sensorimotor" repetitive behavior category. Similarly, in their analysis of RRBIs as measured by the ADI-R and the Repetitive Behavior Scale-Revised (RBS-R), Bishop and colleagues (2013) found evidence for a distinction between Insistence on Sameness (IS) and Repetitive Sensory-Motor (RSM) behaviors. A two-factor structure of RRBIs has prior research support (Cuccaro et al., 2003; Shao et al., 2003; Szatmari et al., 2006), while others have found evidence for a third distinct factor, Circumscribed Interests (Lam et al., 2008).

Compounding primary symptoms of ASD are common comorbidities related to cognition (Matson and Shoemaker, 2009) and mental health (Brereton et al., 2006; Gillott et al., 2001; Kim et al., 2000; Marriage et al., 2009; Rattaz et al., 2015). While the severity of primary and comorbid features fluctuates across the spectrum, research has targeted variation in higher order cognition known as executive dysfunction as a key comorbidity associated with ASD (Demetriou et al., 2017; Pennington and Ozonoff, 1996) that relates to restricted and repetitive behaviors and interests (Mosconi et al., 2009; Mostert-Kerckhoffs et al., 2015), social symptoms (Leung et al., 2016; Lieb and Bohnert, 2017), and overall quality of life (De Vries and Geurts, 2015).

Executive functioning (EF) encompasses higher order cognitive abilities, including directed attention, working memory, planning, flexibility, and inhibitory control (Burgess and Simon, 2005; Chan et al., 2008; Diamond, 2013). Inhibitory control, or the ability to suppress interfering external distractions ("interference suppression") and motor responses ("behavioral inhibition"), is considered a fundamental executive process (Diamond, 2013; Fuster, 2008; Nigg, 2000). Inhibitory control underlies the development of other executive functions (Barkley, 1997), and predicts school, occupational, and social success (Diamond, 2013) while poor inhibition contributes to several psychological disorders, including attention deficit hyperactivity disorder (ADHD) (Nigg, 2000), mania (Murphy et al., 1999), addiction (Feil et al., 2010), and ASD (Turner, 1999). Another integral facet of EF is cognitive flexibility, which includes set-shifting or the ability to transition from one task or mental set to another (Diamond, 2013; Miyake et al., 2000). Poor set-shifting can lead to perseveration on strategies that are no longer adaptive or relevant to a given task (Ridderinkhof et al., 2002). More broadly, cognitive inflexibility has been implicated in a number of psychological disorders, including obsessive compulsive disorder (Chamberlain et al., 2006; Gu et al., 2007), eating disorders (Tchanturia et al., 2004; Tchanturia et al., 2012), and ASD (e.g. Van Eylen et al., 2011).

Studies of inhibitory control in ASD have presented mixed findings, although many studies indicate that both reduced behavioral inhibition and interference suppression are present in ASD throughout the lifespan (see Geurts et al., 2014 for meta-analysis). This meta-analysis, which analyzed studies of behavioral (i.e., prepotent) response inhibition and interference suppression in ASD and typically developing control groups, detected a medium effect size for behavioral inhibition and a small effect for interference suppression, with age moderating the effect of behavioral inhibition and IQ moderating studies of interference suppression. Others have shown that participants with ASD were less able to slow their reaction time (i.e., proactive slowing) in order to work more carefully during difficult parts of tasks (Schmitt et al., 2017). Within and across studies of inhibitory control in ASD, inconsistent findings may reflect task difficulty (e.g. Go/No-Go; see Chan et al., 2011; Han and Chan, 2017) and the sensitivity of reported variables (e.g., length of Stop Signal warning durations; see Schmitt et al., 2017) rather than preserved inhibitory functioning in ASD. Discrepant findings may also result from different age ranges used across studies and related developmental changes in inhibitory control (e.g., Schmitt et al., 2017; Van den Bergh et al., 2014).

Underlying inhibitory control deficits have been postulated to contribute to the maintenance of interfering or nonadaptive thoughts and behaviors that are characteristic of RRBIs in ASD (Turner, 1997; 1999). Evidence for a relation between inhibitory control and RRBIs generally, and higher order RRBIs specifically, in individuals with ASD is mixed (Lopez et al., 2005; Mosconi et al., 2009; Schmitt et al., 2017). Supporting a more nuanced relationship between inhibitory control and RRBIs, Mosconi and colleagues (2009) found that impaired inhibitory control, as measured by prosaccade errors (saccades toward a target) in the gap overlap task, were associated with the “higher order” subtype of RRBIs (e.g. restricted interests, compulsions, preoccupations), but not repetitive sensorimotor behaviors. Further, Schmitt and colleagues (2017) demonstrated that the ability to accurately inhibit dominant responses on a Stop Signal Task was related to RRBIs, particularly compulsive and ritualistic behaviors, whereas the reduced ability to slow oneself and exert greater cognitive control over the task was related to higher levels of stereotypies and clinician observed RRBIs (but see Hogeveen et al., 2018). Thus, measuring different aspects of inhibition (i.e., behavioral inhibition, interference suppression, proactive slowing) may clarify the complex relation between inhibition and RRBIs in ASD and help resolve these mixed results.

Despite a compelling theoretical link between the behavioral rigidity readily observable in ASD and the cognitive inflexibility that is hypothesized to underlie it, investigations into cognitive inflexibility in ASD have also been mixed (for reviews, see Geurts et al., 2009 and Yerys et al., 2009). Geurts and colleagues (2009) identify several possible explanations for these discrepant findings, including underpowered sample sizes and the selection of different cognitive flexibility measures across studies. For example, although the Wisconsin Card Sorting Task (WCST) consistently captures performance deficits in ASD, it has been criticized as a measure of cognitive flexibility due to its concurrent working memory and social demands (Van Eylen et al., 2011). Using a task designed to address these confounds, Van Eylen and colleagues (2011) found significantly more perseveration errors and a higher switch cost in with participants with ASD compared to typically developing controls.

Multiple studies have linked the perseverative features of RRBIs to similar measures of cognitive inflexibility in ASD (De Vries and Geurts, 2012; Lopez et al., 2005; Yerys et al., 2009). De Vries and Geurts (2012) found that a subset of ASD participants with higher rates of repetitive behaviors made more omission errors on a gender-emotion switch task compared to participants with lower rates of repetitive behaviors. Similarly, in a study of children with ASD without cognitive impairment, Yerys et al. (2009) found overall RRBI symptoms significantly related to errors made during a reversal set-shifting trial of an Intradimensional/Extradimensional Shift Task. These authors did not investigate the relation between shifting deficits and higher order versus sensorimotor RRBIs. Finally, using a probabilistic reversal learning task that required integration of implicit information in order to shift from one response set to another, D'Cruz and colleagues (2013) demonstrated that youth and young adults with ASD who made more regressive errors of returning to the original response set following a reversal had higher levels of parent reported stereotyped behaviors, need for routine, and difficulty with transitions. Similarly, children and adults with ASD who experienced more regressive errors on a computerized set-shifting task also had a higher level of RRBIs (Miller et al., 2015).

Work examining the combined impact of multiple EF subdomains to RRBIs is quite limited in ASD. In a sample of 17 adults with ASD, Lopez and colleagues (2005) analyzed a composite measure of the restricted, repetitive scores taken from observational measures and parent report against a battery of EF tasks. Findings showed that response inhibition, working memory, and cognitive flexibility all significantly related to restricted and repetitive symptoms when examined separately. However, cognitive flexibility (comprised of perseverative responses on the WCST and letter-number switching on the California Trail Making Test) was the only predictor of RRBIs when the three EF domains were combined in a single model.

Taken together, mixed results of investigations of inhibition and set-shifting are also consistent with the possibility that heterogeneity in ASD includes individual differences in EF ability. Several groups have investigated the extent to which these EF skills contribute to RRBIs, however less is known about their relationship to distinct RRBI categories. This study seeks to identify whether phenotypic variation in RRBIs, specifically higher order versus sensorimotor RRBs, relates to impaired inhibitory control and set-shifting in behavioral tasks and parent report of executive functioning in children with ASD. We build on prior work (e.g., Lopez et al., 2005) which highlights the theoretical importance of testing the contribution of multiple EFs to RRBIs across a variety of EF tasks. Given the evidence that inhibition and set-shifting both contribute to RRBIs, particularly higher order RRBIs, we predict that both will uniquely contribute to the severity of higher order RRBIs but not sensorimotor behaviors. The study included inhibitory measures of interference suppression and behavioral inhibition as well as measures of cognitive flexibility between a dominant and alternative response and perseverative errors. Following the suggestion of Kenworthy and colleagues (2008), the battery also included a widely-accepted parent report measure of real-world executive functioning in addition to lab-based tasks.

Method

Participants were 102 children (11 female) with ASD between 7- to 11-years-old. Children were recruited in a university setting in the Pacific northwest and at a hospital setting New England using existing recruitment registries, community events, clinics serving children with ASD, and word of mouth. All children had existing diagnoses of ASD, which were rigorously confirmed using the Autism Diagnostic Observation Schedule, Second edition (ADOS-2; Lord et al., 2012), the Autism Diagnostic Interview-Revised (ADI-R; Rutter et al., 2003) according to Collaborative Programs of Excellence in Autism (CPEA) criteria (see Sung et al., 2005 for details), and DSM-5 (American Psychiatric Association, 2013) criteria based on expert clinical judgement. All children had cognitive ability of 80 or above as assessed by the Wechsler Abbreviated Scale of Intelligence-2 (WASI-2; Wechsler, 2011) and were verbally fluent (See Table 1 for participant characteristics). Exclusionary criteria were assessed via a screening phone call and included severe sensory or motor impairments that limited the ability to complete the test battery, inability to complete questionnaires or testing sessions in English, medical disorders or medications that impact the central nervous system, prolonged prenatal substance exposure, and a history of seizures or use of seizure medication. The Human Subjects Divisions at both institutions approved all study procedures and all parents consented for their children to participate.

Executive Function Battery.

Behavioral tasks were administered via laptop computer to evaluate executive function performance.

Stroop Task.—The Stroop Task (Perlstein et al., 1999; Stroop, 1935) is a measure of the ability to inhibit interfering information. After first screening for colorblindness, children completed 20 practice trials with squares presented one trial at a time in four different colors: red, blue, green and yellow. Then, 16 practice trials included neutral words (dog, bear, tiger, monkey) presented in the four font colors. Neutral words were the same length as the color words. Finally, the test block included 96 trials presented in pseudorandom order with three conditions: (1) congruent trials (25%) with a color word written in the same color (e.g., *blue* in a blue font); (2) incongruent trials (25%) with a color word written in one of the other colors (e.g., *blue* in a red font); and (3) neutral trials (50%) with a non-color word in one of the four colors (e.g., *bear* in a blue font). Button presses indicated the color of the text. The difference between percent correct for congruent and incongruent conditions was the dependent variable. Higher scores represented reduced interference control. Data were available for 93 children after excluding data for children who were colorblind (n=3) or unable to complete the task (n=6).

Change task.—The Change Task (De Jong et al., 1995; Geurts et al., 2004) is adapted from the Stop Task. It measures inhibition of dominant responses, proactive slowing, and some aspects of cognitive flexibility. Children completed either a version with an auditory or a visual stop signal[1]; differences between versions were detected only for proactive slowing, $t(91)=-2.77$, $p=.007$. A practice reaction time block presented a picture on either the right or left side of the screen and children indicated the side via button press. A stop practice block included a stop signal (i.e., either a beep or a color change to a central image) that preceded a subset of items. For trials with a stop signal, children were told to suppress their responses. A practice change block followed, in which a stop signal preceded a subset of items and children were told to suppress the dominant response and press a different button (i.e., the

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[1] A larger proportion of children were able to complete the visual version of the task.

change response). To adjust for individual differences in RT during the task, each child's mean correct reaction time from the change practice block was used to determine the mean anticipated RT of the first test block. Subsequent blocks used the mean correct reaction time of the previous block. Across four test blocks, 25% of trials included stop signals that required a change response and 75% were go trials. An equal number of stop signals occurred at 50, 200, 350, and 500 ms before the child's anticipated response. Four types of variables were measured. Stop signal reaction time (SSRT)[2] measures the latency of inhibitory responding (Band et al., 2003; Crone and van der Molen, 2004). A related variable is the percent correct during change trials, which require the inhibition of a dominant motor response in order to complete the change response. This variable complements the SSRT because it does not adjust for the reaction time during the dominant task, and instead captures only the accuracy of responses with relatively different inhibitory difficulty–from 50 ms to 500 ms warning. Indeed, the best opportunity to observe cognitive flexibility follows a successful inhibition for trials with the longest (i.e., 500 ms) warning. An additional aspect of proactive inhibition, or slowing during the task to accommodate more careful responding to stop signals relative to baseline responding, was computed by subtracting the correct reaction time for Go trials during baseline from the correct reaction time for Go trials during the task. Finally, the number of perseverative errors following a shift response (i.e., pressing the response key for a change response on consecutive non-change trials) was examined as a measure of cognitive flexibility. Higher SSRT and perseverative responses and lower accuracy and proactive inhibition latency indicated more difficulty with inhibition and shifting. Data were available for 93 children due to task difficulty.

BRIEF.—Real-world executive function was measured with the Behavior Rating Inventory of Executive Function (BRIEF; Gioia et al., 2000), which yields Inhibit and Shift subscales within the Behavioral Regulation Index. One parent declined to complete the BRIEF.

Restricted and Repetitive Behavior Scores.

Individual item responses obtained during the ADOS-2 and ADI-R were combined to form composite scores for the restricted and repetitive behavior domain. In particular, these composites were created to separate higher order and sensorimotor composite scores. The higher order composite included the sum of raw scores from current observation of intense or unusual interests and ritualistic behavior on the ADOS-2 combined with reported lifetime severity of these behaviors on the ADI-R. Higher scores represent higher levels of RRBs. Specific higher order items and subscales included:

ADOS-2 D4. Excessive Interest in/References to Unusual or Highly Specific Topic +

ADOS-2 D5. Compulsions or Rituals +

ADI-R-2 C1. Encompassing Preoccupation or Circumscribed Pattern of Interest +

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[2] For outliers due to chance performance, the intermediate inhibition function value was replaced with the minimum or maximum value, as appropriate, before adjusting for mean RT.

ADI-R-2 C2. Apparently Compulsive Adherence to Nonfunctional Routines or Rituals As noted by Bishop and colleagues (2013), ADOS-2 item D4 is an “impure” measure of higher order RRBIs (i.e. insistence on sameness) due to its inclusion of behaviors that fall into the sensorimotor category. Specifically, item D4 includes both repetitive interests and persistent aversive reactions to sensory stimuli. To address this issue, we analyzed all ADOS-2 D4 item endorsements for behaviors that could be categorized as sensorimotor. Only two children were noted to exhibit sensory aversions in our sample. One appeared to respond negatively to the sounds of some toys and the other complained that a sensory experience during the ADOS-2 ‘made his hair stand up.’ Bishop and colleagues (2013) found that sensitivity to noise (e.g. aversive reaction to sensory stimuli) loaded onto the IS factor rather than the Repetitive Sensory Motor factor, supporting the inclusion of this item in the higher order category of RRBIs.

The sensorimotor composite was similarly comprised of the sum of clinician observed sensory interests and repetitive motor mannerisms during the ADOS-2 combined with reported lifetime severity of stereotyped motor movements and preoccupation with parts or nonfunctional aspects of objects. Specific sensorimotor items and subscales included:

ADOS-2 D1. Unusual Sensory Interest in Play Material/Person +

ADOS-2 D2. Hand and Finger and Other Complex Mannerisms +

ADI-R C3. Stereotyped and Repetitive Motor Mannerisms +

ADI-R C4. Preoccupation with Parts of Objects or Nonfunctional Elements of Material We examined the distribution of these new scales given the somewhat heterogeneous sample of participants with respect to cognitive ability. As shown in Figure 1, both scales were normally distributed without outliers with variability in function in the RRBI domain.

Analysis plan.

We first confirmed that all variables were normally distributed and then examined the pattern of Pearson correlations between Higher Order RRBIs, Sensorimotor RRBs and the executive function battery. Because Perseverative Errors on the Change task were not normally distributed, Spearman correlations were examined for this variable. First, we examined inhibitory variables and set-shifting variables separately. Then, we entered executive function variables that were significantly related to RRBIs into a hierarchical linear regression model with age, full-scale IQ, or task type entered in the first step, executive function measures second, and RRBIs as the dependent variable. Age and IQ were included when correlated with EF measures being tested to ensure that results were not due to underlying variation in age and intelligence.

Results

Inhibition.

We first examined the pattern of correlations within inhibitory EF. Stroop congruent-incongruent difference scores related to Higher Order RRBIs, $r(93) = .258$, $p = .013$, but not to Sensorimotor RRBs (p=.63). During the Change Task, Stop Signal Reaction Time was unrelated to Higher Order RRBIs (p=.20) or Sensorimotor RRBs (p = .07). As expected, accuracy differed by warning duration, M_{50} = 0.19, SD = .14, M_{200} = 0.26, SD = .18, M_{350} = 0.40, SD = .22, M_{500} = 0.57, SD = .25. The four warning durations were examined separately controlling for multiple comparisons (p=.0125). None of the warning delays significantly related to higher order RRBIs (ps>.042), but lower accuracy at the 200 ms warning delay significantly related to Sensorimotor RRBs, r(93) = −.314, p = .002. Similarly, increased proactive inhibition during the Change Task was unrelated to Higher Order RRBIs (p=.82), but related to lower Sensorimotor RRBs, r(93) = −.301, p = .003. Finally, BRIEF Inhibit scores were positively related to Higher Order RRBIs, r(101) = .243, p = .014, but not Sensorimotor RRBs (p=.09).

In order to determine whether these measures of inhibition uniquely contributed to variance within Higher Order RRBIs, a regression was computed. Age and IQ were entered in the first step, given that Full Scale IQ related to Stroop difference scores, r(93) = −.236, p = .023, with differences between the congruent and incongruent condition decreasing with intelligence, and age significantly related to worse BRIEF Inhibit scores, r(101) = .304, p = .002. Stroop difference scores and BRIEF Inhibit were entered in the second step and Higher Order RRBIs were the dependent variable. In this model (Table 2), Stroop scores significantly predicted Higher Order RRBIs above and beyond age and IQ, whereas BRIEF Inhibit did not account for unique variance beyond the Stroop in this model.

Likewise, in order to determine whether both measures of inhibition uniquely contributed to Sensorimotor RRBs, proactive inhibition during the Change Task and accuracy on Change trials with 200 ms warning durations were entered into a regression. Age was entered in the first step, given that age significantly related to better accuracy inhibiting on Change trials with 200 ms warning delays, r(93) = .212, p = .041. Task (auditory vs. visual stop signal) was also included in the model, given that it related to proactive inhibition. In this model (Table 2), lower proactive inhibition predicted higher levels of Sensorimotor RRBs, whereas accuracy for trials with 200 ms warning did not significantly account for additional variance.

Set-Shifting.

The percent of failures to shift when given 500 ms warning during the Change Task was not related to either Higher Order RRBIs (p = .206) or Sensorimotor RRBs (p = .315). Likewise, Perseverative Errors were not related to either Higher Order RRBIs (p= .686) or Sensorimotor RRBs (p = .540). BRIEF Shift, r(101) = .295, p = .003, was positively related to Higher Order RRBIs, but not to Sensorimotor RRBs (p = .675). Although the BRIEF Shift score was unrelated to Age and IQ, the relations approached significance (ps=.069 and .054, respectively), and a regression was computed to confirm that it significantly predicted Higher Order RRBI scores above and beyond these variables. In this model (Table 3), BRIEF Shift scores significantly predicted Higher Order RRBIs above and beyond age and IQ.

Testing Independent Contributions of Inhibition and Set-Shifting.

The inhibition and shifting variables that predicted Higher Order RRBIs in separate analyses (i.e., Stroop Difference scores and BRIEF Shift) were entered into the second step of a regression model in order to examine whether each uniquely contributed to Higher Order RRBIs (the outcome variable). Age and IQ were controlled in the first step. In this model, both interference suppression and parent reported shifting ability uniquely accounted for variance in higher order RRBIs (see Table 4).

Discussion

This study had the goal of examining the relation between restricted and repetitive behaviors and executive function. In particular, the distinction between higher order RRBIs compared with sensorimotor behaviors was of interest. As well, we examined whether two aspects of executive function uniquely contributed to RRBIs – inhibitory control and cognitive flexibility. We found that increased higher order RRBIs specifically relate to reduced inhibition of conflicting information and flexibility among school-aged children with ASD, and that both account for unique variability in higher order RRBIs above and beyond age and IQ. Additionally, reduced proactive inhibition related to higher levels of sensorimotor RRBs. These findings are significant because they suggest that, although executive function does not specifically account for the full constellation of RRBI symptomatology as once theorized, individual differences in both inhibition and shifting ability appear related to the severity of these symptoms.

Within the inhibitory domain, performance on the Stroop, a lab-based measure of interference suppression, predicted severity of higher order RRBIs beyond age and IQ, whereas parent report of real-world inhibitory control and impulsivity on the BRIEF Inhibit sub-scale did not account for unique variance. Thus, lab-based interference suppression appears to be sensitive to the aspect of inhibition that most contributes to higher order RRBIs. Our finding is consistent with prior work that found a relation between the ability to suppress saccades to targets and higher order RRBIs (Mosconi et al., 2009). This suggests that the ability to control attention by suppressing interfering stimuli that cue a repetitive behavior, interest, or desire for sameness, rather than the ability to inhibit the corresponding RRBI behavior, is most critical to predicting whether a child with autism engages in higher order RRBIs. Additionally, the ability to recognize the need to work carefully during challenging tasks and proactively slow one’s responding relative to baseline related to lower levels of sensorimotor restricted and repetitive behaviors. Thus, consistent with prior work (Schmitt et al., 2017), a measure of cognitive control of response speed appears more closely related to the ability to suppress unusual sensory and repetitive motor responses.

With respect to cognitive flexibility, we found that parent report on the BRIEF Shift scale, a broad, real-world measure of the ability to move from one situation, activity, or part of a problem to another as needed (including the ability to transition, tolerate changes, flexibly problem solve, or shift attention) related to higher order RRBIs, whereas neither accuracy on trials of the lab-based Change Task with the longest warning to inhibit dominant responses and shift to another response (i.e., 500 ms trials) nor perseverative errors following change trials were related to higher order RRBIs. No relations were detected with sensorimotor

RRBs. BRIEF Shift remained a significant predictor of higher order RRBIs when age and IQ were controlled. Although the Change Task provides an opportunity to capture both inhibition and cognitive flexibility, it is important to note that our battery did not include more traditional measures of set-shifting or reversal learning, which would have enabled the measurement of regressive errors. The ability to shift to a new rule or response without reverting to the previous response has been linked to lower levels of routinized and ritualistic behaviors, difficulty with transitions, and repetitive speech (D'Cruz et al., 2013; Miller et al., 2015). Previous work also demonstrated an association between cognitive flexibility and a specific aspect of compulsive, body-focused RRBs (Flessner et al., 2015). Nonetheless, our battery suggests that a wider range of flexible behaviors and responses to situations (i.e., the BRIEF Inhibit sub-scale), rather than the cognitive ability to disengage from a dominant response and follow a different rule or the ability to shift back to the dominant task following a rule change, is more closely tied to engagement in higher order RRBIs among children with ASD.

Lastly, in a model that combined inhibition and shifting variables, both BRIEF Shift scores and lab performance on the Stroop measure of interference suppression accounted for unique variance in higher order RRBIs above and beyond age and IQ, suggesting that both abilities contribute to the expression of higher order RRBIs. This extends the work of Lopez and colleagues (2005), by demonstrating the ability to engage in selective attention and "tune out" stimuli unrelated to the task at hand *and* the ability to shift attention, transition smoothly, and flexibly problem solve both contribute independently to higher order RRBIs. Unlike the broad RRB composite used by Lopez (2005), the current study provides evidence of a specificity within these EF subdomains and Higher Order RRBs. Of note, in the current model, higher order RRBIs were not significantly predicted by age or IQ, which were included in the first step, suggesting that the associations between inhibition, set-shifting and RRBIs represent more stable individual differences in symptom expression during childhood that are less impacted by general aspects of cognition than they are by specific aspects of executive function.

Examining subdomains within EF and RRBIs is consistent with evidence of distinctions in the underlying neural representation of these complex behaviors. Prior reports suggest different functional anatomy underlies performance during the Stroop and Switch tasks (Schmitz et al., 2006). This research lends support to the possibility of independent and specific neural systems that contribute to reduced executive function and increased symptom impairment among children with ASD. In addition, our findings highlight the importance of distinguishing higher order RRBIs from sensorimotor behaviors. Animal models of these behaviors shed light on potential differences in the underlying neural representation of these symptoms in ASD. For example, the BTBR T+ tf/J mouse strain has difficulty with both probabilistic reversal learning, a measure of flexibility and shifting, as well as repetitive burying and grooming behavior, a measure of 'insistence on sameness' (Amodeo et al., 2012, but see Pearson et al., 2011). In terms of repetitive self-grooming, decreased volume of the striatum, globus pallidus, and thalamus correlated with more time spent self-grooming. These results are consistent with converging human neuroimaging evidence, which implicates striatal substructures in RRBIs. For example, in a group of 17 adults with ASD, Hollander and colleagues (2005) found that putamen and right caudate volumes were positively correlated with both higher and lower order RRBIs, though this relationship was particularly strong for higher order symptoms. These authors suggest that the OCD-like pattern of behaviors and interests in ASD may result from striatal abnormalities shared by the two disorders (Hollander et al., 2005). Conversely, research with preschool-aged children with ASD found increased RRBI symptoms in general were associated with *decreased* putamen volumes (Estes et al., 2011). Finally, Padmanabhan et al. (2015) found increased activation of the putamen and other regions among individuals with ASD relative to control participants without ASD during an inhibitory (i.e., antisaccade) task. Taken together, findings suggest a relationship between striatal structures, RRBIs, and inhibition; however, this relationship appears to change from early childhood to early adulthood.

Although the present study adds information about the specific aspects of executive function that contribute together to variability in RRBIs, it is not without limitations. First, the cross-sectional design with school-aged children limits our ability to understand the developmental trajectories of inhibitory control and cognitive flexibility in ASD. Thus, it remains possible that the relationship between RRBIs and specific EF domains observed in our childhood sample may normalize in adolescence or adulthood or have a different relation with RRBIs at other stages of development. While recent research suggests that inhibitory impairments in ASD indeed persist into adulthood and likely remain stable (Uzefovsky et al., 2016), it is unclear how their relationship to higher order RRBIs may change over time. Further, our composite variables included ADI-R algorithm items, which capture the lifetime presence of RRBIs, but do not emphasize sensitive measurement of concurrent RRBIs. Future research should consider a longitudinal design to allow for developmental conclusions.

Second, our sample lacked much of the heterogeneity observed in the disorder, particularly with respect to the proportion of females and the inclusion of only children without intellectual disability. While autism disproportionally affects males at a rate of 4.5:1 (Christensen, 2016), females comprised less than 10% of our sample. Consequently, our sample was too small to permit analysis of sex-differences in our EF domains of interest. Further, recent research suggests that RRBI symptoms are not as predictive of ASD diagnoses in girls as in boys (Duveskot et al., 2017). Thus, the RRBI symptom category may function differently between genders and consequently have a different relationship to EF. Similarly, our sample was relatively homogenous with respect to language and cognitive ability. Initiatives that capture the broad range of functioning in autism are integral to the generalization of research findings to the spectrum as a whole or to the diverse subgroups within ASD. For example, recent research found that EF and cognitive ability in preschool have differential relationships to the development of play skills, depending on a child’s language abilities (Faja et al., 2016). These findings suggest that the relationship between EF and other domains of functioning varies across the spectrum.

Finally, our EF battery is not comprehensive and instead focused primarily on two domains of EF, inhibitory control and cognitive flexibility, with a theoretical link to RRBIs. In a large meta-analysis of EF in ASD, Demetriou et al. (2017) found executive dysfunction across all EF domains, with no single domain indicating more or less impairment than the others. That said, a prominent body of research, including our own investigation, indicates impairments in inhibitory control and cognitive flexibility exist in ASD and relate to RRBIs. Our measurement battery combined both real-world measures and lab-based tasks of EF and RRBIs, which is desirable in evaluating the EF of children with ASD (Kenworthy et al., 2008). Nonetheless, it is possible the BRIEF may be sensitive to not only EF, but also RRBIs among children with ASD given the similarity of individual items across both types of measures. Inspection of items on the BRIEF also highlights the intersection of EF with language, social, and motivational demands involved with the real-world executive behaviors being rated. Our results suggest that very specific aspects of inhibition uniquely relate to higher order and sensorimotor RRBs. It is possible that a more specific set of lab-based measures of cognitive flexibility and set-shifting would reveal a similar pattern. Indeed, the Change Task requires both inhibition and shifting within each change trial, making it difficult to fully disentangle the relative contributions of each. Alternatively, it is possible that broad, real-world measures of flexibility best predict the kinds of challenges related to RRBIs, such as insistence on sameness. Future work is needed to resolve these possibilities. Finally, other aspects of EF and other factors beyond EF may be predictive of the severity of RRBIs including attention (Hogeveen et al., 2018) and comorbidities such as anxiety (Cashin & Yorke, 2018). Further research is required to elucidate the relationship between EF, autism symptoms, and frequently co-occurring disorders and cognitive profiles, with a particular need for research that represents the full autism spectrum longitudinally.

In summary, this study provides evidence for the distinct contributions of inhibition of interfering stimuli and behavioral flexibility to individual differences in higher order RRBIs among children with ASD, whereas proactive inhibition related to sensorimotor RRBs. Despite general cognitive performance in the average range or above, the presence of difficulties with the cognitive domain of EF appears to be clinically important to the severity of core behavioral symptomatology in ASD. This finding has potentially important clinical implications for screening specific aspects of EF: interference suppression, proactive inhibition, and behavioral flexibility. As well, it suggests that EF may be an important predictor of intervention response and a potential target for interventions aimed at RRBIs (e.g., Boyd et al., 2012).

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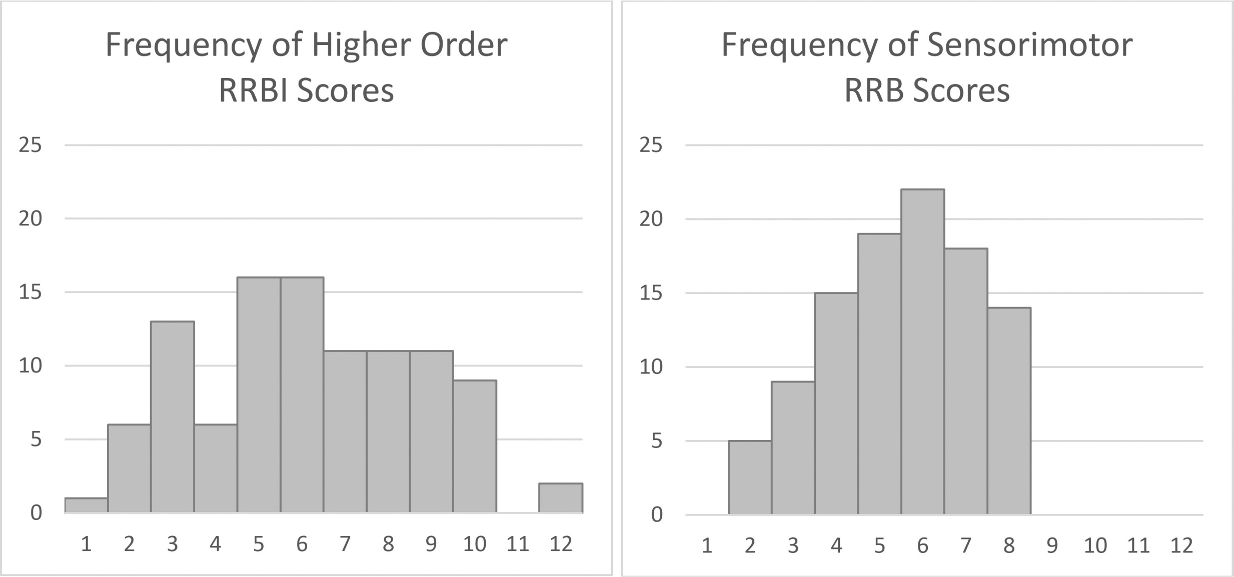

Figure 1.

Frequencies of higher order RRBIs and sensorimotor RRB symptoms (ADI-R and ADOS-2 composite scores)

Table 1.

Participant Characteristics ($N = 102$)

	M	Range (SD)
Age (in months)	110.27	84–144 (16.55)
WASI-2		
Full Scale IQ	106.08	80–150 (14.29)
Verbal Comprehension Index	104.92	69–160 (15.75)
Perceptual Reasoning Index	106.29	69–141 (14.78)

Table 2.

Regression Models of Inhibitory EF Predicting Higher Order and Sensorimotor RRBs

Variable	B	SEB	β	R^2 or ΔR^2
Predicting Higher Order RRBIs				
Step 1				.008
Age	.014	.016	.088	
FSIQ	.003	.019	.018	
Step 2				**.095****
Age	.006	.016	.038	
FSIQ	.010	.019	.058	
BRIEF Inhibit	.033	.022	.160	
Stroop Difference Score	**6.097**	**2.602**	**.249***	
Predicting Sensorimotor RRBs				.024
Step 1				
Age	−.006	.011	−.063	
Task Type	.514	.397	.136	
Step 2				**.148*****
Age	.002	.010	−.007	
Task Type	.819	.392	.216*	
Change Proactive Slowing	**−.003**	**.001**	**−.282***	
Change % Correct 200 ms	−1.764	1.054	−.186	

[*] $p < .05$

[**] $p \leq .01$

[***] $p \leq .001$

Note: this pattern of findings remained identical when age and IQ were not included.

Table 3.

Regression Model of Shifting EF Predicting Higher Order RRBIs

Variable	**B**	**SE B**	**β**	***R^2* or *ΔR^2***
Predicting Higher Order RRBs				
Step 1				.008
Age	.013	.015	.086	
FSIQ	−.004	.018	−.021	
Step 2				**.086****
Age	.005	.015	.035	
FSIQ	−.013	.017	−.076	
BRIEF Shift	**.059**	**.020**	**.303****	

* $p < .05$

** $p \leq .01$

Table 4.

Regression Model of Inhibitory and Shifting EF Predicting Higher Order RRBIs

Variable	**B**	**SE B**	**β**	R^2 **or** ΔR^2
Predicting Higher Order RRBs				
Step 1				.008
Age	.014	.016	.088	
FSIQ	.003	.019	.018	
Step 2				**.119**[**]
Age	.008	.016	.049	
FSIQ	.004	.019	.024	
Stroop Difference Score	**5.959**	**2.555**	**.243**[*]	
BRIEF Shift	**.045**	**.021**	**.227**[*]	

[*] $p < .05$

[**] $p \leq .01$

Note: this pattern of findings remained identical when age and IQ were not included.