RELATIONSHIP BETWEEN REPETITIVE BEHAVIORS AND EXECUTIVE FUNCTION IN HIGH FUNCTIONING CHILDREN WITH AUTISM

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By

LINDSAY E. KESTER

Dr. Shawn Christ, Thesis Supervisor

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The undersigned, appointed by the dean of the Graduate School,

have examined the Thesis entitled

RELATIONSHIP BETWEEN REPETITIVE BEHAVIORS AND EXECUTIVE FUNCTION IN HIGH FUNCTIONING CHILDREN WITH AUTISM

Presented by Lindsay E. Kester

A candidate for the degree of

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And hereby certify that, in their opinion, it is worthy of acceptance.

Professor Shawn Christ

Professor Yuyan Luo

Professor Stephen Kanne

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ABSTRACT

Background: Restricted, repetitive, and stereotyped patterns of behavior, interests, and activities are a core symptom cluster of autism spectrum disorder (ASD). To the extent that patients with executive dysfunction related to prefrontal cortex injury also demonstrate repetitive behaviors, it has been theorized that impairments in executive function may contribute to the repetitive behavior symptomatology associated with ASD as well. Prior attempts to evaluate this theory have yielded mixed results, with only a handful of studies reporting evidence of a relationship between executive function ability and repetitive behavior symptomatology. A critical commonality across these 'positive' studies appears to be their utilization of complex behavioral measures (e.g., Wisconsin Card Sorting Test) that place concurrent demands on multiple executive processes (e.g., inhibitory control, working memory).

The present study was designed to further elucidate the nature of the relationship between ASD-related impairments in executive function and manifestation of repetitive behavior. Specifically, we evaluated the hypothesis that repetitive behavior symptomatology would be most closely related to behavioral task performance under conditions placing concurrent demands on multiple executive processes (i.e., inhibitory control + task switching) as compared to conditions in which demands were placed on only one executive process at a time (i.e., inhibitory control or task switching).

Methods: A sample of 22 children (mean age: 14.4 years) with high functioning (IQ > 70) ASD were recruited. An eye movement task was utilized to assess inhibitory

control and cognitive flexibility concurrently and individually. Participants were presented with a central fixation point flanked on both sides by a peripheral box. When the participant was properly fixated, the central point was replaced with either a red or green colored "X" or a red or green colored "O" to indicate whether the participant should respond with a prosaccade or an antisaccade once a peripheral box was brightened. In addition to the traditional antisaccade conditions, further inhibitory demand was added to some of the trials by manipulating the length of time between the offset of the central fixation and the onset of the peripheral stimulus. Each of these critical trial types were intermixed and counterbalanced to produce five executive function conditions (moderate inhibition, high inhibition, switching only, moderate inhibition and switching, and high inhibition and switching) as well as a neutral condition in which minimal executive ability was required.

The primary caregiver for each participant was interviewed to obtain current and lifetime measures of the repetitive behaviors exhibited by the participant. The Autism Diagnostic Interview (ADI), a semi-structured interview, was administered as a means of confirming an Autism diagnosis for each participant and items from the repetitive behavior section of the ADI were also included in some of the analyses. The Repetitive Behavior Scale (RBS) was the primary measure of repetitive behavior symptomotology for this study. The RBS is a parent questionnaire that addresses the occurrence of a wide range of repetitive behaviors within the past month.

Results: A repeated measures ANOVA confirmed the overall effectiveness of the three manipulations (prosaccade/antisaccade, gap/overlap, and repeat/switch).

Hierarchical regression was the primary method of analysis used to determine the relationship between repetitive behavior symptomotology and executive dysfunction while controlling for differences in age and processing speed. In general, we found significant relationships between repetitive behaviors as measured by the RBS and performance on the eye movement task only in conditions which placed demands on multiple executive abilities. Conditions that required only a single executive ability (e.g., moderate inhibition and switching only trials) were not significantly related to the RBS. In contrast to other published results, we did not find a significant relationship between performance on the eye movement task and repetitive behavior symptomotology as measured by the ADI.

Conclusions: The relationship between repetitive behavior and executive dysfunction appears to depend critically upon the introduction of multiple executive demands. Within this context however, increased task difficulty may also play a role in strengthening this relationship. Investigating this relationship is one future direction of this line of research.

Keywords: Antisaccade, Autism Spectrum Disorder, cognitive flexibility, executive function, inhibitory control, repetitive behaviors.

Relationship between Repetitive Behaviors and Executive Function in High Functioning Children with Autism

INTRODUCTION

Autism Spectrum Disorder (ASD) refers to a spectrum of developmental disorders characterized by difficulties in three domains: reciprocal and non-verbal communication, social interactions, and restricted repetitive and stereotyped patterns of behavior, interests, and activities (American Psychiatric Association, 2000). Within the domain of repetitive behaviors, symptoms exhibited by individuals with ASD may include repetitive motor behaviors such as hand flapping or spinning, and/or fall in the category of restricted, circumscribed interests that are unusual in content or intensity for the individual’s age. Such behaviors often vary in type and severity among individuals with ASD. Repetitive behaviors may interfere with the ability of individuals with ASD to perform successfully in both social and academic settings.

It has been hypothesized that impairments in underlying cognitive abilities such as inhibitory control and task switching may contribute to the repetitive behaviors associated with ASD (Russell, 1997). Individuals with ASD may be unable to inhibit the tendency to continue to engage in a particular behavior despite negative social consequences (Turner, 1997). Additionally, they may continue to engage in repetitive behaviors, despite receiving negative feedback, because of a difficulty switching from the current response or mode of thinking (Ridley, 1994; Turner, 1999).

Executive Function

Inhibitory control and cognitive flexibility, along with several other cognitive abilities, are considered "executive" functions. Executive function is an umbrella term given to a set of higher order cognitive abilities that allow individuals to control and modify their behavior and which involve the integration of information across a wide variety of sources (Stuss, 2002). Traditionally, clinical neuropsychologists have used tests such as the Wisconsin Card Sorting Test (WCST) to evaluate various executive functions in individuals with and without brain injury/dysfunction.

The WCST, considered a classic neuropsychological test of executive function, was originally developed in 1948 by Esta Berg and is one of the most commonly used measures of cognitive flexibility (Berg, 1948; Demakis, 2003). The standard form of the WCST is administered with very few instructions. The examiner presents the patient with a target card and instructs him or her to match the card with one of four indicator cards. Each of the target cards could be sorted based on one of three dimensions—color, form, or number. No information is provided as to which sorting category is correct. The patient must determine the proper sorting rule through a process of trial and error. The examiner only provides feedback after each response as to whether the target card was properly sorted. Once the patient has successfully sorted 10 consecutive cards, unbeknownst to him/her, the sorting rule is changed and what was previously correct becomes an incorrect response. The patient must again use trial and error to determine the proper category by which to sort the target cards. As the task progresses, the sorting rule is changed in a similar fashion up to five more times (the three categories listed above are each completed twice) or until the card deck (128 cards) has been entirely depleted. A number of scores are obtained from the WCST. The most common scores of interest include: total number and percentage of perseverative errors, total number of categories completed and total number and percentage of errors.

Recently, a confirmatory factor analysis by Miyake and colleagues (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000) investigated the extent to which set shifting (cognitive flexibility), updating (working memory), and inhibition of a prepotent response (inhibitory control) may represent somewhat distinct component processes that comprise a unitary construct of executive control. To this end, they examined participants' performance on a series of nine experimental tasks (each of which was purported to tap one of the three aforementioned component processes) and five complex executive tasks that are believed to require multiple executive abilities. As predicted, confirmatory factor analysis established that a three factor model provided the best fit suggesting that these abilities are distinguishable from one another. To address the question of the degree to which these three component processes may contribute to performance on more complex tests of executive function (such as those mentioned previously), additional analyses were conducted. The results suggest that, whereas each complex task (e.g., WCST) appeared to tap one of the three target processes most prominently, each of the tasks was well explained by a three factor model comprised of switching, updating and inhibition factors. Thus, multiple executive processes appear to contribute to performance on these complex tasks.

Evidence from animal, patient, and neuroimaging research indicates that the prefrontal cortex (PFC) and related regions play an important role in executive functions (Miller & Cummings, 2007). With regards to the three aforementioned component processes, recent meta-analyses of neuroimaging data (Buchsbaum, Greer, Chang, & Berman, 2005; Christ, Van Essen, Watson, Brubaker, & McDermott, 2009) suggest that while there is significant overlap in the brain regions associated with the three executive processes (particularly in the dorsolateral prefrontal cortex), there are also subset(s) of brain regions uniquely implicated in each process (e.g., working memory: right posterior parietal; inhibitory control: ventral anterior cingulate cortex; task switching: posterior occipital cortex).

Using an activation likelihood estimation (ALE) method of meta-analysis, Buchsbaum and colleagues (2005) also evaluated the extent to which the brain regions activated during performance of the WCST corresponded with those associated with more discrete tests of inhibitory control and task switching. Significant overlap, particularly in regions of the PFC, was revealed between the WCST ALE map and the maps of the two aforementioned component processes. Taken together with the previously described findings of Miyake et al. (2000), this finding provides converging evidence that multiple component processes, including inhibitory control and task switching, contribute to performance on WCST and other complex executive tasks.

Executive Function in Autism

Russell (1997) and others have hypothesized that PFC dysfunction and consequential impairment in executive control may represent a core deficit in ASD. This theory is supported by the similarities in clinical presentation (particularly the manifestation of repetitive behaviors) between patients with overt damage to the PFC and individuals with ASD. In line with this theory, structural and neurophysiological irregularities have been documented in PFC among individuals with ASD (for review, see Brambilla et al., 2003). Functional neuroimaging studies have also documented atypical patterns of activation in the PFC regions during performance of both executive and nonexecutive tasks (for reviews, see Cody, Pelphrey, & Piven, 2002; Minshew & D. L. Williams, 2007). Support for executive dysfunction hypothesis from behavioral studies of executive control and ASD, however, has been mixed.

For example, whereas some studies have found ASD-related impairments on inhibitory control tasks (Christ, Holt, White, & Green, 2007; Joseph, McGrath, & Tager-Flusberg, 2005; Beatriz Luna, Doll, Hegedus, Minshew, & John A Sweeney, 2007), others have reported comparable inhibitory performance for individuals with and without ASD (Goldberg et al., 2005; Lopez, Lincoln, Ozonoff, & Lai, 2005; Schmitz et al., 2006). Building on work by Friedman and Miyake (2004) and others suggesting that inhibitory control may be best conceptualized as comprising at least three different components (inhibition of a prepotent response, resistance to distracter interference, and resistance to proactive interference), recent research in our lab (Brubaker, Christ, & Miles, 2009; Christ et al., 2007) has shown that individuals with ASD demonstrate circumscribed impairments in the ability to resist distractor interference (as reflected by poor performance on Flanker visual filtering tasks) but the ability to inhibit a prepotent response and the ability to resist proactive interference are generally intact among individuals with ASD. One exception to this, however, appears to be oculomotor prepotent response inhibition, which has been consistently found to be impaired in individuals with ASD (Minshew, B. Luna, & J. Sweeney, 1999; Mosconi et al., 2009; Thakkar et al., 2008).

Oculomotor prepotent response inhibition is typically measured using an antisaccade paradigm. A typical antisaccade task consists of a prosaccade condition and an antisaccade condition. In both conditions, the participant is fixated at a central location until a peripheral stimulus appears in the left or the right visual field. Following the presentation of the peripheral stimulus, the participant is instructed to make an eye movement either toward the peripheral stimulus (prosaccade) or to a mirror location in the opposite visual field (antisaccade). A prosaccade (looking toward the onset of a novel stimulus) is a highly reflexive response. For this reason the prosaccade is typically used as a baseline measure against which the participant's performance on the antisaccade condition is compared. The antisaccade condition requires inhibition of a reflexive response in favor of a voluntary eye movement and is used as a measure of oculomotor inhibition.

A number of studies have documented ASD-related impairments in oculomotor inhibition as evidenced by slowed response time and/or increased direction errors in the antisaccade condition for individuals with ASD as compared to typically developing controls (Goldberg et al., 2002; Minshew et al., 1999; Mosconi et al., 2009; Thakkar et al., 2008). In some studies (van der Geest, Kemner, Camfferman, Verbaten, & van Engeland, 2001; Goldberg et al., 2002; Mosconi et al., 2009), researchers also manipulated the presence/absence of a temporal gap (e.g., 200 ms) between the offset of the central fixation and the onset of the peripheral target so as to evaluate whether group-related differences varied based on the strength of the inhibitory demand. Inhibitory demands are thought to be greater when such a 'gap' is present as compared to when there is overlap (i.e., the fixation is not removed prior to target presentation). Consistent with this, both individuals with and without ASD show increased inhibitory errors in the gap condition as compared to the overlap condition (van der Geest et al., 2001; Goldberg et al., 2002; Mosconi et al., 2009). Of note, van der Geest and colleagues (2001) reported a slightly smaller effect of the gap/overlap conditions among individuals with ASD. Other studies (Goldberg et al., 2002; Mosconi et al., 2009) have failed to find group-related differences related to this manipulation.

Cognitive flexibility has long been considered an area of particular weakness for individuals with ASD. Of note, this assertion is largely built upon past studies utilizing the WCST as the measure of choice for cognitive flexibility (Bennetto, Pennington, & Rogers, 1996; Minshew, Goldstein, Muenz, & Payton, 1992; Ozonoff & McEvoy, 1994; Voelbel, Bates, Buckman, Pandina, & Hendren, 2006; Winsler, Abar, Feder, Schunn, & Rubio, 2007). Given the previously described research implicating other executive component processes (e.g., working memory, inhibitory control) in WCST performance, it is possible that observed ASD-related difficulties on the WCST are not due solely to task demands on cognitive flexibility per se, but rather the compounded demands the task places on cognitive flexibility, working memory, and inhibitory control. Consistent with this, recent research (Goldberg et al., 2005) has found that individuals with ASD perform comparably to typically developing individuals on the Extradimensional/Intradimensional Shift (ED/ID) subtest from the CANTAB battery (Robbins et al., 1998, 1994), a test designed to assess cognitive flexibility in a more isolated manner. This task measures the ability to attend to certain elements of complex, multidimensional stimulus pictures and flexibly shift attention from one attribute to another. For the first several trials of the task, the participant is instructed to attend to a certain aspect of the stimuli and ignore the other elements. After the participant becomes accustomed to focusing on one attribute, the instructions change and the participant must attend to the previously irrelevant attribute. When demands are placed only on a single component process, individuals with ASD have demonstrated ability to maintain the resources required to perform sufficiently. This pattern of results provides support for the possibility that cognitive flexibility may be impaired among individuals with ASD to a degree that is only detectable when compounded with other executive demands.

The Relationship between Repetitive Behavior and Executive Function in Autism

Although a conceptual link has been proposed between repetitive behaviors and executive function, the nature of any such relationship remains unclear in that only a handful of studies have reported significant findings in this regard. In one such study, South, Ozonoff, and McMahon (2007) found a significant relationship between measures of repetitive behaviors and performance on the Wisconsin Card Sorting Test (WCST) in a sample of individuals with high functioning ASD (n = 19) relative to healthy control participants (n = 18). Repetitive behaviors were measured as a composite score based on three sources of information: the Repetitive Behavior Interview (RBI), the Yale Special Interests Interview (YSII) and diagnostic criteria from the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV). The RBI and YSSI are both semi-structured caregiver interviews that allow the interviewer to rate the frequency and severity of a number of repetitive behavior symptoms. The repetitive behavior portions of the Autism Diagnostic Interview-Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994a) and the Autism Diagnostic Observation Schedule-General (ADOS-G; Lord et al., 2000) were also included in the analysis. The number of perseverative responses was the primary measure of interest from the WCST. Individuals with high functioning autism were compared with control participants matched on age and level of intellectual ability. The results indicated that performance on the WCST was significantly correlated with the repetitive behavior portions of the ADOS and ADI-R (poorer WCST performance = higher degree of repetitive behaviors), but was not related to the RBI or YSII.

Another study by Lopez and colleagues (2005) also explored the relationship between repetitive behaviors and executive abilities in individuals with and without ASD. Seventeen adults with ASD (ages 19-42 years) and seventeen healthy controls (ages 18-45 years) were administered a battery of executive tests purported to measure cognitive flexibility (WCST and Trails B), working memory (a letter-number sequencing task), inhibitory control (Stroop color-word task), and fluency (verbal fluency and design fluency tasks). Repetitive behaviors were measured using the ADI-R, ADOS-G, Gilliam Autism Rating Scale (GARS), and the Aberrant Behavior Checklist (ABC). The researchers examined the correlation between a computed composite score for each executive domain and a similarly computed composite score for repetitive behaviors. Interestingly, they found that working memory, inhibition, and cognitive flexibility composite scores were negatively correlated with the repetitive behavior composite score (poorer performance = higher degree of repetitive behaviors); however, the fluency score was not.

Additional evidence for a relationship between repetitive behavior and executive function comes from a recent study by Kenworthy and colleagues (Kenworthy, Black, Harrison, Della Rosa, & Wallace, 2009). Using archival data from an interdisciplinary clinic, Kenworthy et al. (2009) found a significant relationship between executive functions and all three aspects of ASD (i.e., social, communication and restricted, repetitive behaviors) in 89 children with ASD (ages 6-17 years). Scores from the ADI-R and ADOS-G were aggregated to produce composite scores for the three categories of autism symptoms. They then evaluated the relationship between these composite scores and performance on an extensive battery of neuropsychological tests (e.g., Behavior Rating Inventory of Executive Function, BRIEF, a parent report of every day executive function; Tower of London, a spatial test requiring planning and sequencing; a measure of semantic fluency; subtests from the Test of Everyday Attention for Children, TEA-C). With regards to the BRIEF, they found that the metacognition index score (MCI) was related to social symptoms and that the behavior regulation index (BRI) score was related to all three symptom categories. A significant relationship was also evident between restricted, repetitive behaviors and response inhibition (walk-don't walk); however this relationship did not persist above and beyond the effects of age. Participants performed most poorly relative to normative scores on the Tower of London test; however this test of multiple executive abilities (planning, response inhibition and working memory) was not significantly related to any of the ASD symptom categories.

Each of the aforementioned studies has noted a relationship between executive abilities and repetitive behaviors; however the measures (e.g., WCST) used in these studies represent broad and complex measures of executive control. One possible explanation for why measures such as the WCST have shown significant relationship to repetitive behaviors is that they imitate the complex nature of daily activities requiring the simultaneous use of multiple abilities. For example, it is unlikely that complex tasks such as grocery shopping would place demands on working memory alone.

Within this context, it remains difficult to delineate the extent to which repetitive behaviors are related to specific executive component processes (e.g., inhibitory control, working memory, cognitive flexibility). One potentially viable approach to this issue is to utilize laboratory measures, which are gleaned from experimental cognitive psychology and are designed to measure isolated cognitive processes, to assess specific aspects of executive function. Along these lines, another recent study by Mosconi et al. (2009) investigated the relationship between inhibitory control (by visually guided saccade and antisaccade tasks) and repetitive behaviors (obtained from the diagnostic algorithm items on the ADI-R). Participants were 18 individuals ages 8 to 54 years, with high functioning ASD (IQ>80) and 15 age and IQ-matched healthy controls ages 8 to 55 years.

The eye movement task was conducted using electrooculogram (EOG) technology in which saccades were detected by electrodes and measured based on muscle contractions. Trials within each condition were blocked by condition (prosaccade and antisaccade) and the antisaccade condition always followed completion of the prosaccade condition. The researchers determined that practice was not needed for the prosaccade condition due to the reflexive nature of the task (making an eye movement toward the onset of a peripheral stimulus); however ten practice trials were administered (and repeated if needed) prior to the antisaccade condition. In addition to the prosaccade and antisaccade conditions, gap/overlap conditions and onset location of the stimulus were manipulated. In the gap condition, the central fixation marker was removed 200 ms before the onset of the peripheral stimulus and in the overlap condition the central fixation remained until after the stimulus had appeared. The gap condition was expected to facilitate a release of the visual fixation system and thus allow the participant to shift attention more quickly. Location of the peripheral stimulus was manipulated to appear at three different distances from central fixation. Within each block of trials (prosaccade and antisaccade), the gap/overlap and distance conditions were interspersed such that participants received a total of 36 trials of each condition.

In evaluating the extent of restricted, repetitive behaviors exhibited by participants, the authors made a distinction between two subtypes of repetitive behaviors. Sensorimotor repetitive behaviors were measured by items C3 and C4 on the diagnostic algorithm including stereotyped motor mannerisms and repetitive, non-functional use of objects. Higher-order repetitive behaviors were defined as unusual and circumscribed interests as measured by items C1 and C2 on the diagnostic algorithm. Examples of higher-order repetitive behaviors include intense and seemingly all-consuming interests that appear odd or unusual for the individual's age or compulsive or ritualistic behaviors. Saccadic latency and number of direction errors (antisaccade condition only) within each condition (gap/overlap and location of stimulus) were examined for group differences and then analyzed to determine the extent to which performance was related to the two categories of repetitive behaviors.

Overall, participants showed reduced latency on the gap condition, but there was no group difference in this condition. Both groups made more direction errors when the stimulus was presented closer to the central fixation; however this effect was disproportionally larger for the ASD group. In terms of the relationship between the eye movement task and repetitive behavior symptoms, only higher-order repetitive behaviors were significantly related to the number of direction errors made by participants in the antisaccade condition. Interestingly, no significant relationship was found between the index of sensorimotor repetitive behaviors and antisaccade performance. A proposed explanation for this distinction was the fact that higher order repetitive behaviors are a unique symptom associated with ASD, whereas sensorimotor repetitive behaviors are seen in many other disorders.

The Current Study

The present study was designed to replicate and extend the findings of Mosconi et al. (2009) as well as those of the previously described studies. Specifically, the current study utilized a pro/antisaccade task and a battery of repetitive behavior measures to systematically study the relationship of repetitive behaviors to (1) inhibitory control, (2) cognitive flexibility, and (3) the combination of the two executive function components.

As noted above, in the Mosconi et al. (2009) study, the prosaccade (PS) and antisaccade (AS) conditions were administered in a blocked fashion, with the block of prosaccade trials always followed by the block of antisaccade trials. In contrast, in the present study PS and AS trials were interspersed within the same blocks. This allowed the evaluation of not only inhibitory control (overall difference in PS and AS performance), but also cognitive flexibility (difference between PS trials following another PS trial and PS trials following AS trials) as well as situations placing demand on both executive processes (AS trials following a PS trial).

The current study also expanded on other aspects of Mosconi et al.'s (2009) methodology:

(1) The present study employed a larger, more homogeneous sample of ASD participants (N = 22, age range = 8-18 years) than that utilized in the Mosconi et al. study.

(2) Whereas Mosconi et al. used EOG to track eye position, we utilized a video-based method relying instead on combined pupil and corneal reflection. This method was preferred due to the significantly stronger signal to noise ratio and relative accuracy and stability of the calibration as well as convenience and noninvasiveness of the apparatus. EOG methodology has been criticized as being susceptible to interference due to eye blinking and changes in skin resistance and requires that the environment maintain a very consistent illumination because the corneoretinal potential is susceptible to change with variation in ambient lighting (Deuschl & Eisen, 1999). Video-oculography is the least invasive oculomotor technique and may be more tolerable for a population with ASD because there is no need for participants to be attached to any apparatus or wear any invasive device that obstructs a portion of the visual field. The camera is mounted just below the display screen (approximately 2 ½ feet from the participant) and a small chin and forehead rest are in place to maintain constant distance. Participants can take breaks as needed and readily resume the task often without recalibration.

(3) In addition, participants in Mosconi et al.'s study were afforded only minimal practice (no practice for PS condition; as few as 10 trials of practice for AS condition). It remains possible that, with additional practice, participants with ASD may have performed more comparably to their control counterparts. Within this context, the present study contains extensive opportunity for practice prior to administration of the experimental trials.

(4) In the Mosconi et al. study, the target could appear in any of six (3 per side) unmarked locations on the display. The additional memory load related to this aspect of the methodology may have inadvertently influenced the outcome of the study. Indeed, previous studies have shown that concurrent nonverbal memory load can have a detrimental effect on antisaccade performance (Roberts, Hager, & Heron, 1994). In the present study, we sought to minimize the secondary non-verbal memory load by utilizing only 2 potential target locations (1 per side), each of which was marked by a placeholder.

(5) Similar to Mosconi et al.'s study, our eye movement task included a gap/overlap manipulation in which the central fixation marker either remained present or was extinguished 200 ms prior to the presentation of the peripheral stimulus. By including this manipulation, we added an additional degree of inhibitory demand to that of the traditional AS paradigm.

(6) Lastly, as compared to Mosconi et al., the present study utilized a measure of repetitive behaviors with a far more extensive array of items and behavior categories.

Based on the past ASD studies of executive control and repetitive behaviors, we anticipate that the extent and severity of repetitive behavior symptomatology (as evaluated by parent report on the Repetitive Behavior Scale) will be related to individual performance in the combined (inhibitory control + task switching) condition but not the single component (inhibitory control or task switching) conditions of the present task. In short, we hypothesize that it is a combination of abilities, rather than individual abilities that is related to difficulties with repetitive behaviors.

METHODS

Participants

A sample of 22 children with high functioning ASD participated in the study. Participants (21 males, 1 female) ranged in age from 8 to 18 years old (*M* = 14.4, *SD* = 2.4). They were recruited through the University of Missouri Thompson Center for Autism and Neurodevelopmental Disorders, an interdisciplinary academic medical center specializing in diagnosis and treatment of ASD. Diagnosis was further confirmed via the Autism Diagnostic Interview-Revised (ADI-R; Lord et al., 1994a). Overall intellectual ability was estimated using the Wechsler Abbreviated Scale of Intelligence (WASI; Psychological Corporation, 1999). Full scale IQs for participants ranged from 73 to 116 (M = 96.7, *SD* = 14.1). All participants received $50 as compensation for their time.

Materials and Procedure

The present study was approved by the University of Missouri-Columbia Internal Review Board. The current study consisted of two parts: (1) a behavioral study component and (2) a care-giver interview study component. Participation took approximately 3 hours and included measures of general cognitive ability, repetitive behaviors, and adaptive functioning. Participants had the option of completing this study over multiple sessions, and participants were given frequent breaks to rest between tasks.

All of the measures described below have been well-established in the neurocognitive literature and have been successfully administered within clinical pediatric populations (Bodfish, Symons, Parker, & Lewis, 2000; Christ, Steiner, Grange, Abrams, & White, 2006; Christ, White, Brunstrom, & Abrams, 2003; Lord, Rutter, & Le

Couteur, 1994b). The antisaccade eye movement task was administered on computer, and response times (RT) and error rates for each eye movement was recorded. This task also included a baseline condition to control for individual differences in non-executive abilities (e.g., processing speed). The measures that require parent interview were conducted in person by a trained researcher.

Measures

Autism Diagnostic Interview. The Autism Diagnostic Interview Revised (ADI-R) (ADI-R; Lord et al., 1994a) was administered to the parent or caregiver of the participant by a trained researcher. The ADI-R is a structured interview which focuses on current and past behavior in terms of four areas of difficulty associated with an ASD diagnosis: (1) Qualitative abnormalities in reciprocal social interactions, (2) Qualitative abnormalities in communication, (3) Restricted, repetitive, and stereotyped patterns of behavior and (4) Abnormalities of development evident before 36 months. The ADI-R diagnostic algorithm has been used throughout the literature to confirm ASD diagnosis and is appropriate for individuals with a mental age equal to or greater than 24 months. In addition to providing diagnostic information, items from the repetitive behavior subscale were used to measure repetitive behaviors demonstrated by participants.

Repetitive Behavior Scale. Along with relevant questions from the ADI-R, the Repetitive Behavior Scale (RBS; Lam & Aman, 2007), was used to measure the type and severity of repetitive behavior symptoms exhibited by the participants. The RBS is a parent questionnaire that categorizes repetitive behaviors into six subscales: (1) Stereotyped Behavior, (2) Self-injurious Behavior, (3) Compulsive Behavior, (4) Ritualistic Behavior, (5) Sameness Behavior and (6) Restricted Behavior. Previous studies (e.g., Bodfish et al., 2000) have established the RBS as a reliable measure of repetitive behaviors among individuals with autism spectrum disorders.

Eye Movement Task. An eye movement task was used to measure two aspects of executive control: inhibitory control and task switching. The apparatus and procedure are similar to that used in previous studies (Christ et al., 2006). Participants were seated in front of a computer monitor with their heads steadied by a chin rest. The sequence of visual events in each condition was identical, differing only in terms of the initial stimulus indicating the response set for the subsequent trial.

Participants were presented with a central fixation dot flanked 8° to the left and right by 1° peripheral boxes. After 300 ms, the fixation dot was replaced by either a red or green colored "X" or a red or green colored "O" indicating whether the following response should be a prosaccade or an antisaccade eye movement. (The precise cue-response mapping was counterbalanced across participants. For one participant, a red X and green O might be associated with prosaccade and antisaccade conditions, respectively. For the next participant, it might be a green X for the prosaccade condition, and a red O for the antisaccade condition and so on.)

Insert Figure 1 here

Following a delay of 850 ms, one of the flanking boxes was brightened. In the *prosaccade* condition, the participants were asked to make a reflexive eye movement toward the brightened box as quickly as possible. In the *antisaccade* condition, participants must inhibit the reflexive response and instead look at the unbrightened box as quickly as possible. We also included a gap/overlap manipulation. In the gap condition, the central fixation point was extinguished 200 ms before the flanking box was brightened. In the overlap trials, the central fixation remained present throughout the trial. [Introduction of an empty "gap" immediately before presentation of the peripheral stimulus on antisaccade trials has been shown to increase the inhibitory demands of the task as reflected by increased error rate and decreased RT (van der Geest *et al*, 2001).]

Following onset of the peripheral stimulus, the visual display remained for 1500 ms, during which time eye position was recorded. After an inter-trial interval of 1000 ms, a new trial was presented. RT was also recorded as the dependent variable for each trial.

Eye movements were recorded using an Eye-Trac R6 remote eye-movement monitor with video head tracking (Applied Sciences Laboratories, Bedford, MA). To determine the onset of saccades, eye movement samples were filtered and differentiated to obtain a smooth record of velocity. A saccade was deemed to have occurred if the velocity exceeded 10°/sec for a period of 32msec or longer. This method is similar to that which we have used previously (Christ, McCrae, & Abrams, 2002; Christ et al., 2003; Christ et al., 2006).

Eye movements that are made within 100 ms after the target is presented were recorded as anticipatory errors. Eye movements that are not initiated within 1500 ms of target onset were recorded as inattentive errors. Accuracy errors were recorded if participants made eye movements in the incorrect direction (e.g., looking toward the brightened box on an antisaccade trial).

The task consisted of 20 practice trials, followed by 192 experimental trials. Experimental trials were grouped in four blocks of 48 trials each. Twenty-four prosaccade and twenty-four antisaccade trials were counterbalanced within each block. Participants were allowed to take breaks between blocks as needed. Participants were informed as to which eye movement to make by the color and shape of a stimulus (either a red X or a green O) presented immediately before the onset of the peripheral stimulus. The eye movement associated with these stimuli was randomly determined across participants such that some participants were instructed to make an antisaccade eye movement when they saw a red 'X' and other participants would make an antisaccade after a green 'O'. (For a given participant, the instructions remained constant during the entire testing session).

The aforementioned intermixing of the trial types resulted in six experimental conditions of most interest:

(1) Neutral Condition (processing speed only)

Prosaccade overlap repeat trial (prosaccade trial following another prosaccade trial). This condition is hypothesized to require minimal executive control and, as such, it served as a baseline to which performance on all other conditions was compared. This was to help control for individual participant differences in processing speed and other non-executive processes.

(2) Moderate Inhibition Only Condition

Antisaccade overlap repeat trial (antisaccade overlap trial following another antisaccade overlap trial). Given that this condition places demands on inhibitory control without requiring the participant to switch response patterns, this trial type measured inhibitory control ability.

(3) High Inhibition Only Condition

Antisaccade gap repeat trial (antisaccade gap trial following an antisaccade gap trial). Combining the antisaccade and gap manipulations creates a compound inhibitory demand without placing demands on switching ability. This condition is considered a high inhibition condition.

(4) Switching Only Condition

Prosaccade overlap switch trial (prosaccade overlap trial following an antisaccade overlap trial). In this case, the participant must switch response patterns, but because the antisaccade is followed by a less demanding prosaccade trial, the inhibitory demand is minimal. This trial type was used to measure switching ability.

(5) Moderate Inhibition + Switching Condition

Antisaccade overlap switch trial (antisaccade overlap trial following a prosaccade overlap trial). This condition combines the moderate inhibitory demands of the antisaccade manipulation with swtiching demands.

(6) High Inhibition + Switching Condition

Antisaccade gap switch trial (antisaccade gap trial following a prosaccade overlap trial). In this condition, participants must inhibit the tendency to make the reflexive eye movement toward the peripheral stimulus and also switch response patterns between the two trials. This trial type was used to assess performance in the presence of demands on both inhibitory control and switching.

RESULTS

The primary method of analyses for this study was hierarchical regression. This method was selected to allow evaluation of the relationship between the various combinations of executive component processes and day-to-day repetitive behaviors while controlling for individual differences in age and non-executive cognitive processes (e.g., processing speed). A series of hierarchical regressions were conducted, with each of the five non-baseline trial types (moderate inhibition only, high inhibition only, switching only, moderate inhibition + switching, high inhibition + switching) serving as the dependent variable in turn.

For each regression, chronological age and performance in the baseline eye movement condition (prosaccade overlap repeat trials) were entered in the first step of the model. [The baseline condition, which measures the speed and accuracy of a reflexive eye movement, was treated as a measure of non-executive cognitive ability (e.g., processing speed) for the individual because of its negligible executive demands.] Overall RBS score was then entered in the second step of the regression. Once age and processing speed were accounted for, the portion of remaining variance in task performance attributable solely to repetitive behaviors could then be identified (i.e., partial correlation; PR^2).

To protect against an increase in the likelihood of a Type 1 error related to multiple comparisons, we confirmed a significant group effect on overall RBS score before proceeding to analyze the contributing sub-scale scores (e.g., sameness, compulsive). This approach was repeated for each combination of performance measure

(RT or error rate) and critical trial type (moderate inhibition only, high inhibition only, switching only, moderate inhibition + switching, high inhibition + switching).

Inhibitory Demands Only

Moderate Inhibition Condition. Overall, no significant relationships were found between repetitive behaviors and performance on the moderate inhibition condition (antisaccade overlap repeat trials). Direction error rate on the antisaccade repeat trials was not significantly related to repetitive behaviors as measured by the overall RBS score (ΔR^2=.042; $\Delta F(1,17)$=.916; p=.352). RT was also not significantly related to current repetitive behaviors as measured by the RBS (ΔR^2=.001; $\Delta F(1,17)$=.017; p=.897). Since the overall RBS scores were not significantly related to performance on this condition, no further analyses were conducted regarding individual subscales.

High Inhibition Condition. Past studies have demonstrated that insertion of a brief time gap between the offset of the central fixation and the onset of the peripheral stimulus in an antisaccade task makes the tendency to orient to the stimulus much more difficult to inhibit (i.e., increases wrong direction error rate). Within this context, we also evaluated the relationship between repetitive behaviors and performance in this "high inhibition" condition (i.e., antisaccade gap repeat trials).

Despite the increased inhibitory demands, the relationship between the RBS overall score and performance in this condition did not approach significance for either error rate (ΔR^2=.002; $\Delta F(1,17)$=.050; p=.825) or RT measures (ΔR^2=.003; $\Delta F(1,17)$=.079; p=.781). Although this condition placed increased demands on inhibitory ability, it engages only a single executive ability. Therefore it is not surprising that performance on this condition did not show any significant relationships with repetitive behaviors.

Switching Demands Only

In the eye movement condition where demands were placed on switching alone (prosaccade repeat trials), analysis showed that error rate was not significantly related to repetitive behavior as measured by the RBS overall score (ΔR^2=.061; ΔF(1,17)=1.448; p=.245). The performance of participants in terms of RT was also not significantly related to repetitive behaviors on the RBS overall score (ΔR^2=.000; ΔF(1,17)=.003; p=.959).

Concurrent Multiple (Inhibitory + Switching) Demands

Combined Moderate Inhibition + Switching Condition. In contrast to the conditions detailed above, this condition placed demands concurrently on two executive processes. Consistent with our hypothesis, analysis revealed a significant relationship between error rate on this condition and RBS overall score (ΔR^2=.169; ΔF(1,17)=4.940; p=.040). Subsequent analyses confirmed significant relationships between performance in this condition and the Sameness (ΔR^2=.237; ΔF(1,17)=7.883; p=.012) subscale of the RBS. Additionally, there was a trend toward significance in the Compulsive (ΔR^2=.143; ΔF(1,17)=4.007; p=.062), and Ritualistic (ΔR^2=.148; ΔF(1,17)=4.184; p=.057) subscales.

No significant relationship was found between mean RT and the RBS overall (ΔR^2=.000; ΔF(1,17)=.002; p=.966).

Combined High Inhibition + Switching Condition. Similar to findings for the Moderate Inhibition + Switching Condition, performance in the current condition (as reflected by direction error rate) explained a significant amount of variance (ΔR^2=.188; ΔF(1,17)=5.381; p=.033) in repetitive behaviors (RBS overall score). Further analyses suggests that this relationship is driven by the stereotyped (ΔR^2=.198; ΔF(1,17)=5.751;

p=.028) and sameness (ΔR^2=.193; ΔF(1,17)=5.564; *p*=.031) behavior subscales. The compulsive behavior subscale approached significance as well (ΔR^2=.139; ΔF(1,17)=3.678; *p*=.072).

No significant relationship was found between mean RT and the RBS overall (ΔR^2=.037; ΔF(1,17)=1.555; *p*=.229).

Relationship to ADI Repetitive Behavior Items (lifetime and current behavior scores)

The ADI was primarily designed to be a diagnostic tool. It is intended to provide a positive or negative diagnosis of ASD rather than a continuous variable with multiple degrees of severity. Each item is scored by the interviewer as being either present or absent based on the caregiver's narrative response. While the raw scores allow for some indication of severity (i.e., 0-3), this variability is lost when scores are converted on the diagnostic algorithm**.** Also, the repetitive behavior algorithm on the ADI is comprised of only 8 items selected from the overall measure. In two cases, the algorithm includes only the higher of two scores.

Despite the aforementioned psychometric limitations, the ADI has served as the primary measure of repetitive behavior for several past studies investigating relationships between executive control and repetitive behaviors (e.g., Lopez et al., 2005; Kenworthy et al., 2009; Mosconi et al., 2009). Therefore, to afford comparison with previous research, all of the aforementioned analyses were repeated with both ADI lifetime and current repetitive behavior algorithm scores serving as an independent variable (instead of RBS score) in turn.[1] In short, we failed to find a significant relationship between ADI scores (past or current) and performance in any of the present task conditions. Additional details on these results are included in Table 1.

Insert Table 1 here

Higher Order and Repetitive Motor Behavior Classifications of the ADI

Mosconi and colleagues (2009) found that performance on an inhibitory eye movement task was related to only one of two subsets of repetitive behavior symptoms (higher order) on the ADI diagnostic algorithm (repetitive motor behaviors were not related). The algorithm form categorizes the items into four groups with two items per category. Mosconi et al. further collapsed the four categories into higher order repetitive behaviors (items C1 & C2), and repetitive motor behaviors (items C3 & C4). Following the analysis procedure described above, we conducted follow-up analyses for each critical condition with higher order and repetitive motor behaviors (Mosconi et al., 2009) as the independent variable. Results are detailed in Table 2.

Insert Table 2 here

In brief, the present analysis yielded only one statistically significant effect and one non-significant trend: A significant relationship was found between repetitive motor

[1] Measures of past or lifetime symptoms of autism may not be significantly correlated with measures of current symptoms (e.g., de Bildt et al., 2004). The severity of repetitive behaviors tends to decrease with age and can be influenced by exposure to behavioral treatments. Therefore, both past and current behavior scores were explored.

behaviors and mean RT in the switching only condition (ΔR^2=.114; ΔF(1,17)=10.562; p=.005). There was also a trend towards a relationship between higher order repetitive behavior score and error rate in the moderate inhibition condition.

DISCUSSION

Individuals with ASD exhibit repetitive behaviors and circumscribed interests that can often interfere with their ability to function in everyday situations. Most of the published evidence in the quest to elucidate the relationship between executive control and repetitive behaviors has been established using complex executive tasks such as the WCST. In the current study, we used an antisaccade eye movement task to explore the relationship between repetitive behaviors and two component processes of executive control (inhibitory control and task switching). In line with existing literature, we hypothesized that the severity of repetitive behaviors exhibited by individuals with ASD would correlate with inhibitory control, but not cognitive flexibility. Additionally, we expected that the relationship between repetitive behaviors and executive control would be strongest when demands were placed on multiple executive abilities.

Consistent with our hypotheses, we found that repetitive behaviors, as measured by the RBS, were significantly related to performance on our executive measures. Critically, this relationship was only seen in the conditions that required multiple executive component processes. Adding a further degree of inhibitory demand within the combined inhibition and task switching condition did not reveal any increase in the amount of variance explained.

Relationship with Single Executive Abilities

Children whose parents reported a greater number of repetitive behaviors on the RBS were not any more likely to have increased direction errors on the moderate inhibition, high inhibition or switching only conditions of the eye movement task than those whose parents reported fewer repetitive behaviors. Although some studies have reported relationships between repetitive behavior symptomotology and cognitive flexibility, it has often been the case that the measures being used (e.g., WCST) actually involve multiple executive processes. When we measured cognitive flexibility in isolation, we found no relationship between performance on the switching only condition and repetitive behaviors as measured by the RBS. This suggests that placing demands on cognitive flexibility alone is not enough to support a relationship between this component process and repetitive behaviors.

Similarly, there was not a significant relationship between repetitive behavior and task performance under the moderate (antisaccade) or high inhibitory (antisaccade + gap) demands. This was unexpected since previous work by Mosconi and colleagues (2009) reported that performance on an antisaccade task was significantly related to a subset of repetitive behaviors (i.e., higher order repetitive behaviors) on the ADI. The discrepancy between Mosconi et al.'s findings and the present study may be accounted for by the dissimilarities in design of the eye movement tasks. Although Mosconi and colleagues sought to measure inhibitory control, their task also included a component of spatial working memory. The antisaccade task inherently involves a working memory aspect by requiring participants to recall the location of the peripheral stimulus and respond with a saccade to the same location in the opposite visual hemifield. Mosconi et al.'s study introduced an additional working memory component by presenting the peripheral stimulus at various distances from the point of central fixation. It is possible that their significant findings were a result of this additional executive demand. In the present study, the peripheral stimulus was presented in a constant location on each side and placeholders were provided for the peripheral stimuli in order to further reduce the demand on spatial working memory.

Of note, the relationship between repetitive behavior and performance on the eye movement task does not appear to be purely a factor of task difficulty. Increasing the difficulty of the task by compounding the inhibitory demand, as in the high inhibitory condition, did not have a significant effect on the relationship. Taken together with the findings from the switching only condition, the present results provide further evidence that demand on a single executive ability is not sufficient to establish a relationship with repetitive behaviors. It also rules out the possibility that the critical manipulation is increased task difficulty rather than the introduction of multiple executive abilities.

Relationship with Combined Executive Abilities

While placing demands on a single component executive process did not explain a significant amount of variance in repetitive behaviors, task conditions in which multiple executive demands were required *were* significantly related to repetitive behavior symptomotology. Increasing the inhibitory demand alone (i.e., moderate inhibition condition vs. high inhibition condition) was not enough; however, when switching was combined with inhibitory demands, there was a significant relationship. We observed that the effect size for the combined moderate inhibition + switching condition was essentially identical to that of the combined high inhibition + switching condition. This suggests that increasing the difficulty of the task does not influence the relationship with repetitive behaviors, even in the presence of multiple executive demands. Future studies should explore the effect of introducing additional executive demands, such as working memory, to determine whether this would produce a stronger relationship with repetitive behaviors.

The findings of the current study compliment existing literature and bring together the theory of executive dysfunction in ASD with performance on laboratory measures and parental reports of difficulties in day-to-day situations. Whereas the theory of executive dysfunction as a core deficit in ASD is well established, laboratory measures have been less consistent. Moreover, the substantiation of an empirical relationship between laboratory (e.g., Stroop color & word test) and survey-based (e.g., Behavior Rating Inventory of Executive Function [BRIEF]; Gioia, Isquith, Guy, & Kenworthy,2000) measures has been problematic. The results reported here provide a method of bridging the gap between laboratory tasks and every-day situations. By placing concurrent demands on multiple component executive abilities, the eye movement task used here may better approximate day-to-day situations in which individuals with ASD exhibit executive difficulties.

RBS Subscale Analysis

After testing for overall effects with the RBS, we conducted subsequent analyses to determine which subscales might be driving the relationship. The sameness subscale was significant in each of the conditions where multiple executive abilities were required. The sameness subscale on the RBS consists of questions related to agitation when activities are interrupted, resistance to changes in the environment, and reliance on routines. This provides support for the theory that executive difficulties may manifest most prominently in one's ability to transition from one activity to another in day-to-day situations. (Ridley, 1994; Turner, 1999).

Although the sameness subscale was the only one that was influential across all of the significant eye movement conditions (moderate inhibition + switching, and high inhibition + switching), one other subscale—the stereotyped behavior scale—was significantly related to performance on the high inhibition + switching condition. This subscale addressed actions that are repeated in a similar fashion and do not appear to serve a distinct purpose (e.g., head, hand or finger movements, as well as sensory behaviors). There were also two subscales of the RBS that approached, but did not reach significance. First, the compulsive behavior subscale approached significance in both the moderate inhibition + switching and high inhibition + switching conditions. Compulsive behaviors are defined on the RBS as repetitive actions performed according to a certain rule (e.g., arranging, repeating routines). Second, the ritualistic subscale showed a trend toward significance in the moderate inhibition + switching condition. This subscale addresses the insistence that activities of daily living be performed in a similar manner.

Although many conclusions must remain speculative at this point, a couple of impressions stand out among the pattern of results. Each of the subscales (Sameness & Stereotyped) that showed a statistical relationship with task performance addresses some degree of a reliance on routine and a need to perform actions in a similar manner. Previous studies have demonstrated that individuals with ASD are impaired on laboratory-based measures of executive function. Evidence from survey measures has also accounted for significant difficulties in switching to new behaviors or routines. The current study merges these two bodies of literature by establishing a relationship between performance in the laboratory and difficulties in day-to-day behavior. Within this context, it appears that the desire to stick to a routine in everyday functioning is correlated with performance on laboratory measures when both inhibitory control and task switching are involved. Future research should expand upon the findings reported here by investigating similar relationships with other aspects of daily functioning (e.g., emotional regulation, adaptive behavior skills, etc.).

Interestingly, the stereotyped subscale, which was significantly related to only the combined high inhibition+ switching condition, was the one subscale that emphasized purposeless behavior. That this subcategory was singularly related to the condition where all three manipulations were combined suggests that both increased inhibitory difficulty (beyond that of the antisaccade manipulation) as well as compound executive demands (inhibition and switching) are integral to this relationship. The antisaccade manipulation without the added difficulty of both the switching and gap manipulations was not enough to create a significant relationship with this subscale. This may be one reason that Mosconi et al.'s study did not see a relationship with repetitive motor behaviors on the ADI (which addresses behaviors similar to those in the stereotyped subscale of the RBS), as his eye movement task did not include a task switching component.

One explanation for the discrepancy between Mosconi et al.'s findings and those of the current study is the presence of multiple executive demands (high inhibition and task switching). Mosconi et al.'s eye movement task contained only the AS manipulation, which primarily measures inhibitory control. Based on this, it would seem that the relationship between executive function and stereotyped repetitive behaviors (or repetitive motor behaviors) is dependent upon the concurrent demands of multiple executive processes. On the other hand, it is also possible that the difference between these two studies is actually a feature of which executive demand was added to the AS manipulation. As previously discussed, Mosconi et al.'s task may have contained an additional executive demand as well (i.e, spatial working memory); however this extra executive demand did not increase the difficulty of the task enough to lead to a significant relationship. This may suggest that the concurrent demand of inhibitory control and task switching is the critical combination required for this particular relationship.

In terms of providing an explanation for the subscales that did not show significant relationship with performance on the eye movement task, we were able to surmise two possibilities at this point. The lack of significant findings in these behavior categories may be due in part to the fact that very few participants endorsed the items under either the self-injurious or restricted behavior subscales. It should be noted also that the restricted behavior subscale contained a very limited number of items which may have contributed to the lack of variance among the results. With very little variation among participant responses on this measure to begin with, it is not surprising that we were not able to explain a significant amount of variance in the results. These behaviors may have been underrepresented in our sample, possibly because of the age of our participants, level of functioning, or exposure to treatment (see limitations section below). Future studies would be wise to broaden recruitment to include individuals with this type of symptomotology.

With regard to the self-injurious subscale, the lack of a significant relationship may be related to the fact that violent behavior toward oneself and others often implicates difficulties with some kind of emotional regulation which was not the focus of this study. Some have reported emotional dysregulation to be a prominent risk factor for violent behavior toward oneself and others (Krakowski, 2003; Newhill & Mulvey, 2002). Since the present study was designed to measure executive function rather than emotional dysregulation, it is not surprising that we did not find a relationship between self-injurious behavior and executive control. Further investigation is needed to clarify the nature of the relationship between emotional regulation among individuals with ASD. The model proposed in this study, in particular the contribution of multiple component executive processes to the manifestation of behaviors in daily functioning, may be aptly applied to this line of research.

Replicating Existing Studies

As noted previously, one of the recent studies to examine this issue was Mosconi et al. (2009). They found that direction error rate was significantly related to higher order repetitive behaviors on the ADI (C3 and C4 from the behavior algorithm). Within the context of the current study however, we were unable to replicate this finding. One reason our study did not find a significant relationship between repetitive behaviors and the ADI might have to do with the fact that in designing our eye movement task, we deliberately minimized any working memory demand. As previously discussed, displaying the peripheral stimulus at varying onset locations would generate a spatial working memory demand as the participant recalled the same location in the opposite hemifield. It is possible that the working memory component in combination with inhibition may be driving the relationship with repetitive behaviors on the ADI. We may have been unable to replicate this finding because the eye movement task in the present study was designed to minimize the spatial working memory demand. In repeating this study, it would be interesting to introduce a similar working memory component to see if a stronger relationship with the ADI might be revealed.

Although Mosconi et al.'s (2009) study focused on past repetitive behaviors, we expected that current repetitive behaviors would be more closely related to current executive abilities. As such, we explored this relationship by conducting analyses using the questions related to current functioning from the repetitive behavior algorithm. Current repetitive behaviors did not show a significant relationship with eye movement performance and it is reasonable to assume reports of current symptoms to be more accurate.

Furthermore, as previously discussed, the ADI was designed as a tool for general diagnosis of ASD and is therefore relatively limited in the number of repetitive behaviors it addresses. Statistically speaking, this may have influenced the power of the ADI to detect certain aspects of repetitive behavior. It is possible that Mosconi et al. may have simply been fortunate to have recruited a sample of individuals who experience these specific symptoms. Since the ADI does not focus specifically on repetitive behaviors, it is not surprising that the ADI was not significantly related to performance on the eye movement task regardless of whether lifetime or current behaviors were being considered.

Limitations

Several limitations and opportunities for further investigation require consideration in this study. To begin, one of the limiting factors of the present study was the relatively small sample size. The results presented above, and their subsequent interpretation are subject to the limitations of this limited sample. Having tested only 22 individuals within an age range of only 10 years may limit the ability of our results to be generalized to the general population of individuals with ASD. For example, the relationship between repetitive behaviors and executive abilities may be much different for very young children (<6 years old) or older individuals(>60). Existing literature has reported that inhibitory control ability among young children and older adults differs significantly from young adults (Christ, White, Mandernach, & Keys 2001). As our sample was limited to children between the age of 8 and 18 years, it would be difficult to generalize our findings to include young children or older adults. Additional studies must be conducted to validate the findings presented here before more certain conclusions can be made as to the nature of the relationship between repetitive behaviors and executive function.

Another limitation of this study is related to the characteristics of this particular cohort. Specifically, our sample consisted of higher functioning (IQ>70), older children and adolescents with ASD. While we sought to recruit across a wide age range (8-18 years), the mean age of our sample was 14.4 years. The age and level of functioning among our participants may have influenced the prevalence and severity of repetitive behaviors among these individuals. Older individuals tend to exhibit fewer noticeable repetitive behaviors than do young children (due to therapy or simply growing out of them). Likewise, the type of repetitive behavior that is most commonly seen among higher functioning individuals may be qualitatively different than that of individuals with lower IQ scores. Since we used an IQ score cutoff of 70, we were unable, within the limitation of the present study, to assess the influence that level of functioning may have on repetitive behavior symptomotology. Further investigation needs to be done to examine these factors.

In addition to overall level of functioning, older participants are more likely to have undergone various interventions and therapies that may have influenced–by way of coping mechanisms or behavior modification techniques–the severity of symptoms exhibited by the participants. Indeed, anecdotal reports from participant's parents suggest that, in several instances, past and/or current treatment had resulted in noticeable decreases in the frequency and severity of repetitive behavior symptomatology currently exhibited by the children. Considering the influence that exposure to treatment, especially behavior based therapies on the repetitive behavior symptomotology, we were fortunate to have found a significant amount of shared variance at all (a humble 17-19%). It is likely that we would have found a much stronger relationship among children who had not been exposed to therapy.

The compound effect of these cohort characteristics almost certainly limited the degree of variance in repetitive behavior symptomotology exhibited by our sample. Recruiting younger, and possibly lower functioning participants is a means by which prospective investigations could address these limitations. The eye movement task utilized in the present study is simple enough that children much younger than those in the current study should be able to understand and perform the task. Of course the individual's level of functioning (i.e., IQ) needs to be considered as well. Young children who also demonstrate cognitive delay may not be able to perform the eye movement task with an acceptable level of accuracy.

As is often the case with autism research, there is a lower limit to the age and level of functioning at which cognitive studies can maintain a reasonable level of validity and generalizability. One inherent challenge in testing lower functioning individuals is determining which repetitive behaviors are attributable to ASD and which may be more generally characteristic of individuals with severe mental impairment. According to a recent study by Bodfish and colleagues (2000), individuals with mental impairment (ranging from severe to profound MR) with and without ASD both showed significant repetitive behavior symptomotology. On the other hand, participants with coexisting ASD and MR tended to demonstrate greater severity in each of the repetitive behavior categories addressed (e.g., compulsive behavior, stereotypy, and self-injury etc.). The fact that repetitive behavior symptomotology is not exclusive to ASD makes it difficult to determine which has greater applicability in the presence of coexisting diagnoses. Further research should be conducted in order to delineate the differences in repetitive behavior symptomotology in disorders such as ASD, MR and possibly OCD as well.

Future Directions/Summary

The current study provides critical evidence concerning the relationship between higher order cognitive functioning and repetitive behavior symptomotology in individuals with ASD. Despite the limitations recognized above, the present investigation successfully established a significant link between two important aspects of Autism Spectrum Disorder (i.e., executive function and repetitive behaviors). Specifically, the current study adds to evidence in support of the argument that inhibitory control as a single component executive ability is not related to repetitive behaviors. Additionally, the results of this study begin to verify that cognitive flexibility, when measured in isolation, is not related to repetitive behaviors. Repetitive behaviors were only related to executive control under conditions where concurrent demands were placed on multiple executive component processes. Furthermore, this relationship was strongest when all three manipulations were combined.

These findings are consistent with recent assertions that executive dysfunction in individuals with ASD may be most evident in day-to-day situations that require the use of multiple executive and non-executive abilities. When executive demands are minimal, individuals with ASD may not exhibit difficulty maintaining the necessary resources to complete a task, but when executive demands are compounded, these difficulties quickly become evident. Daily activities rarely require only a single ability and thus measures of isolated abilities may fail to reproduce, in the laboratory, the same difficulties demonstrated in day-to-day activities. The chief benefit of the current study is that we were able to measure the component executive abilities in isolation and then combine them within the same task, therefore better simulating the complex demands of an everyday situation and establishing a link between cognitive functioning and clinical symptoms of Autism Spectrum Disorder.

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TABLES

Table 1

Hierarchical Regression Analysis Predicting Task Performance from ADI Repetitive Behavior Algorithm (Past & Current) Scores

	ADI-R Past Repetitive Behavior Algorithm Score			ADI-R Current Repetitive Behavior Algorithm Score		
Task Condition	ΔR^2	ΔF^2	*p value*	ΔR^2	ΔF^2	*p value*
Moderate Inhibition Only Condition						
Mean RT	.02	<1	.46	.02	<1	.50
Error Rate	.04	<1	.42	.08	1.8	.20
High Inhibition Only Condition						
Mean RT	<.001	<1	.96	.001	<1	.84
Error Rate	.002	<1	.83	.02	<1	.43
Switching Only Condition						
Mean RT	.01	<1	.39	.003	<1	.67
Error Rate	<.001	<1	.96	.01	<1	.62
Moderate Inhibition + Switching Condition						
Mean RT	<.001	<1	.90	.001	<1	.83
Error Rate	.03	<1	.45	.01	<1	.63
High Inhibition + Switching Condition						
Mean RT	.02	<1	.43	.006	1.0	.64
Error Rate	.005	<1	.76	.002	<1	.85

Table 2

Hierarchical Regression Analysis Predicting Task Performance from ADI-R Higher Order Repetitive Behaviors Score (C1 + C2) and Repetitive Motor Behaviors Score (C3 + C4)

	ADI-R Higher Order Repetitive Behaviors Score (C1 + C2)			ADI-R Repetitive Motor Behaviors Score (C3+ C4)		
Task Condition	ΔR^2	ΔF^2	*p value*	ΔR^2	ΔF^2	*p value*
Moderate Inhibition Only Condition						
Mean RT	<.001	<1	.93	.04	1.2	.29
Error Rate	.13	3.1	.11	.01	<1	.66
High Inhibition Only Condition						
Mean RT	.002	<1	.82	.001	<1	.86
Error Rate	.003	<1	.79	<.001	<1	.98
Switching Only Condition						
Mean RT	.02	<1	.29	.11	10.6	.005*
Error Rate	.003	<1	.80	.007	<1	.72
Moderate Inhibition + Switching Condition						
Mean RT	.002	<1	.76	.001	<1	.88
Error Rate	.01	<1	.58	.01	<1	.58
High Inhibition + Switching Condition						
Mean RT	.02	<1	.44	.003	<1	.74
Error Rate	.003	<1	.82	.002	<1	.83

*p < .05 uncorrected

FIGURES

Figure Captions

Figure 1. Examples of different trial types for the (a) baseline, (b) moderate inhibition only, (c) high inhibition only, (d) switching only, (e) combined moderate inhibition and switch condition and (f) combined high inhibition and switch condition.

Figure 2. Relationship between repetitive behaviors as measured by the RBS and mean direction error rate (%) for conditions that required only a single executive ability. Fit lines represent overall relationship between error rate and repetitive behaviors without controlling for differences in age and processing speed.

Figure 3. Relationship between repetitive behaviors as measured by the RBS and mean direction error rate (%) for conditions requiring concurrent demands on inhibition and switching ability. Fit lines represent overall relationship between error rate and repetitive behaviors without controlling for differences in age and processing speed.

Figure 1. Examples of Trial Types

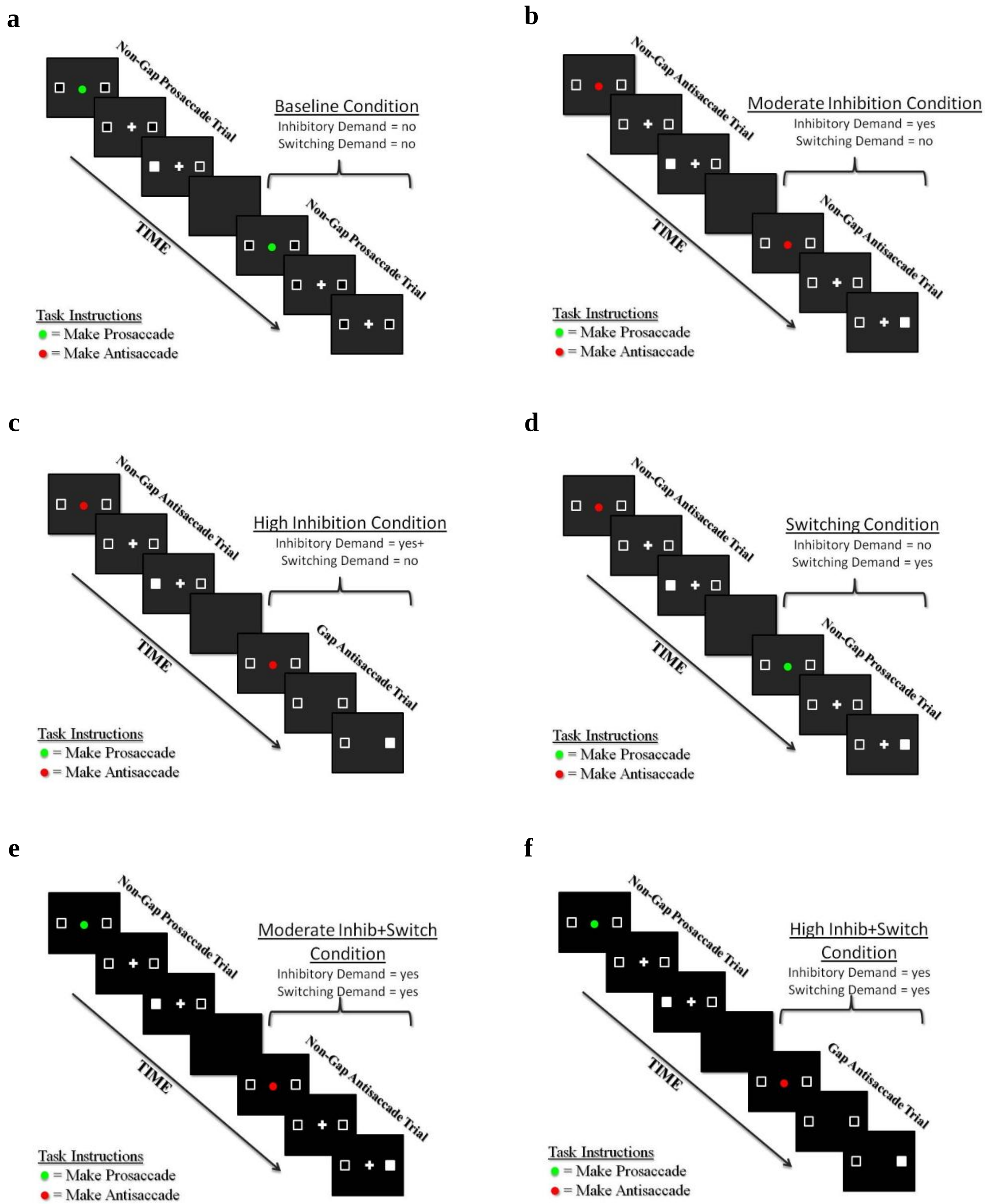
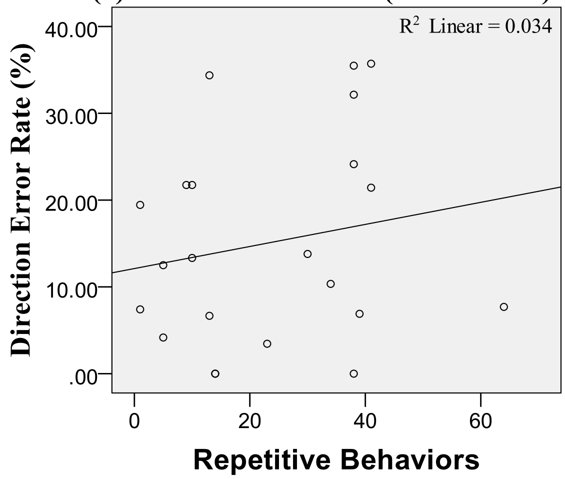
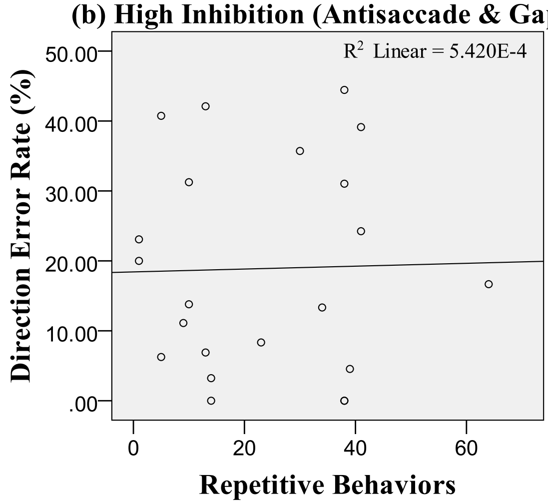


Figure 2. Regression Plots for Single Executive Ability Conditions

(a) Moderate Inhibition(Antisaccade)



(b) High Inhibition (Antisaccade & Gap)



(c) Switching Only (switch)

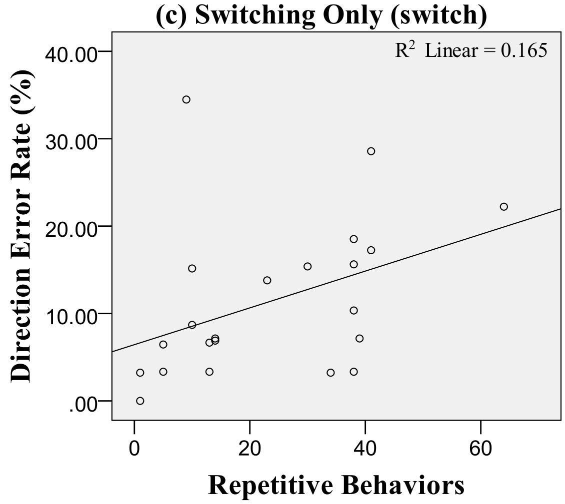


Figure 3. Regression Plots for Combined Executive Ability Conditions