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Inhibitory Control in Children with Autism Spectrum Disorder

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Abstract Impairments in executive abilities such as cognitive flexibility have been identified in individuals with autism spectrum disorder (ASD). It remains unclear, however, whether such individuals also experience impairments in another executive ability: inhibitory control. In the present study, we administered three inhibitory tasks to 18 children with ASD, 23 siblings of children with ASD, and 25 typically developing children. After controlling for individual differences in age, overall IQ, and processing speed, children with ASD demonstrated impaired performance on two of the three inhibitory tasks. Results suggest that children with ASD experience circumscribed deficits in some but not all aspects of inhibitory control. More generally, the findings underscore the importance of using multiple measures to assess a putative single cognitive ability.

Keywords Inhibitory control · Autism · Children · Development · Executive abilities

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Introduction

The term *executive abilities* refers to higher-order cognitive skills such as planning, strategy use, cognitive flexibility, working memory, and inhibitory control (Pennington, 1997; Stuss, 1992). These abilities are considered ''executive'' in that they are said to require the integration and processing of information from a wide range of internal and external sources.

The prefrontal cortex (PFC) appears to play an important role in executive abilities. Animal lesion and human brain-injury studies have reported that impairments in executive abilities frequently are observed following damage to this brain region (e.g., Miller & Cummings, 1999; Milner & Petrides, 1984). Neuroimaging studies also have reported increased activation in the PFC during the performance of tasks requiring working memory, cognitive flexibility, and other executive abilities (e.g., Casey et al., 1997; Konishi, Kawazu, Uchida, Kikyo, Asakura, & Miyashita, 1999). Developmentally speaking, improvements and later decline in executive abilities appear to parallel age-related changes in the neurophysiology of the PFC and its interconnections (e.g., Christ, White, Mandernach, & Keys, 2001; Dempster, 1992; Levin et al., 1991).

Executive impairments are associated with a number of neuropsychological disorders including childhood-onset schizophrenia (Asarnow, Brown, & Strandburg, 1995), obsessive-compulsive disorder (Insel, 1988), attention-deficit/hyperactivity disorder (Casey et al., 1997), Tourette's syndrome (Leckman, Price, Walkup, Ort, Pauls, & Cohen, 1987), and phenylketonuria (Diamond, Prevor, Callendar, & Druin, 1997; Welsh, Pennington, Ozonoff, Rouse, &

McCabe, 1990). Interestingly, PFC abnormalities have been implicated in all of these disorders (Casey et al., 1997; Diamond, Ciaramitaro, Donner, Djali, & Robinson, 1994; Pennington, 1997; Rapoport et al., 1999; Saxena, Brody, Schwartz, & Baxter, 1998).

Past research involving individuals with autism spectrum disorder (ASD) also has documented impairments in higher-level abilities including planning and cognitive flexibility (for an extensive review, see Hill, 2004a). These findings are supported by studies identifying structural, metabolic, and neurotransmitter abnormalities in the PFC of individuals with ASD (Chugani et al., 1997; Ohnishi et al., 2000; Salmond, de Haan, Friston, Gadian, & Vargha-Khadem, 2003). In addition, Luna et al. (2002) reported decreased PFC activity in individuals with ASD as compared to neurologically uncompromised adults during the performance of a spatial working memory task. Delayed PFC maturation in children with ASD also has been reported (Zilbovicius et al., 1995).

Indeed, a number of researchers have postulated that executive dysfunction may be a primary factor underlying many of the cognitive as well as social difficulties experienced by individuals with ASD (for further discussion of this topic, see Hill, 2004b; Russell, 1997). In further support of this theory, proponents point to the fact that several of the atypical patterns of behavior (e.g., tendency to engage in repetitive behaviors) observed following executive dysfunction related to frontal brain injury also can been seen in individuals with ASD. Moreover, it has been proposed that ASD may be distinguished from other neurodevelopmental disorders based on the pattern of sparing and impairment observed across areas of executive ability (e.g., Ozonoff & Jensen, 1999). Within this context, the integrity of inhibitory control in individuals with ASD remains an area of continued contention.

Inhibitory control can be broadly defined as the ability to suppress the activation, processing, or expression of information that would otherwise interfere with the efficient attainment of a cognitive or behavioral goal (Dagenbach & Carr, 1994; Dempster, 1992). Examples of inhibitory control include ignoring competing information while performing a working memory task (Hasher & Zacks, 1988), withholding a prepotent or dominant response (Logan, 1994), or ignoring irrelevant visual information while processing target stimuli (Eriksen & Eriksen, 1974). Given the countless sources of interference encountered on a moment-by-moment basis, intact inhibitory control is essential for navigating and interacting effectively with the environment (Burke, Zencius, Wesolowski, & Doubleday, 1991). Whereas a number of studies have reported significant impairments on measures of inhibitory control in individuals with ASD (e.g., Geurts, Verte, Oosterlaan, Roeyers, & Sergeant, 2004; Minshew, Luna, & Sweeney, 1999; Ozonoff, Strayer, McMahon, & Fillouz, 1994), others have failed to find a difference between individuals with ASD and their control counterparts (e.g., Eskes, Bryson, & McCormick, 1990; Griffith, Pennington, Wehner, & Rogers, 1999; Ozonoff & Jensen, 1999; Ozonoff & Strayer, 1997).

In the present study, we administered three separate measures of inhibitory control to children with ASD, their siblings, and typically developing non-sibling children: Stroop, flanker, and go/no-go tasks. Each of these paradigms is well established in the inhibitory literature (Drewe, 1975; Eriksen & Eriksen, 1974; Stroop, 1935), and each has been administered successfully to individuals with ASD in the past (Eskes et al., 1990; Iarocci & Burack, 2004; Ozonoff & Jensen, 1999; Ozonoff et al., 1994).

In a standard Stroop task, participants are shown a word stimulus and asked to identify the color in which the stimulus is rendered (for an extensive review, see MacLeod, 1991; Stroop, 1935). The correct response may be congruent (e.g., *RED* displayed in the color red), neutral (e.g., *DOG* displayed in the color red), or incongruent (e.g., *BLUE* displayed in the color red) with the identity of the word stimulus. Individuals must inhibit the prepotent reading response and instead identify the color hue of the stimulus. Inhibitory ability is measured by comparing performance for incongruent stimuli with that for neutral stimuli. Past studies of Stroop performance in individuals with ASD have failed to find any group-related differences in inhibitory ability (Eskes et al., 1990; Ozonoff & Jensen, 1999).[1] Of note, however, these previous studies utilized a card version of the Stroop paradigm (e.g., Golden, 1978). In a card version, participants are shown a full page of stimuli at once (e.g., a page of incongruent stimuli followed by a page of neutral stimuli). The overall amount of time needed to respond to an entire page is recorded. Other researchers have used a single-trial version of the Stroop paradigm (Sichel & Chandler, 1969). In this version, stimuli are presented one-at-a-time, presentation of the stimuli is intermixed (e.g., a neutral stimulus could be followed by another neutral stimulus or by an incongruent stimulus), and response time to individual stimuli are

[1] Eskes et al. (1990) interpreted the results of their study in terms of the children's ability to comprehend word meanings and not as evidence of intact inhibitory control per se.

recorded. Recent work with other clinical populations suggests that the single-trial version of the Stroop may be more sensitive to group-related differences than the card-version (Perlstein, Carter, Barch, & Baird, 1998). To maximize our ability to detect potential group differences in Stroop performance, we included both a card version as well as a single-trial version of the Stroop paradigm in the present investigation.

Similar to a Stroop task, a flanker task requires participants to attend to pre-specified visual information while ignoring competing information (Eriksen & Eriksen, 1974). In a typical flanker task, participants respond to the identity of a centrally presented stimulus (e.g., press the left button when the letter ''S'' appears, and press the right button when the letter ''H'' appears). At the time of presentation, the target stimulus is flanked closely to the left and right by distracting stimuli. These stimuli may be either compatible (i.e., mapped to the same response; e.g., *SSS*), neutral (i.e., not mapped to any response; e.g., *XSX*), or incompatible (i.e., mapped to a competing response; e.g., *HSH*) with the target stimulus. Participants must ignore the distractors and instead respond only to the target stimulus. Inhibitory ability is assessed by comparing performance on trials with incompatible stimuli with that on trials with neutral stimuli. A recent attentional-orienting study by Iarocci and Burack (2004) provides evidence that children with ASD can successfully perform a flanker-type task. In that experiment, children were instructed to respond to the identity of a target stimulus. Performance on trials on which the target was presented alone was compared with performance on trials on which the target was flanked by unrelated (i.e., neutral) distractor stimuli. Iarocci and Burack found that children with ASD performed comparably to control children in both conditions. The study, however, did not include an incompatible condition. As a result, the comparison between performance in the no-distractor and neutral distractor conditions of Iarocci and Burack's study likely reflects visual filtering ability rather than inhibitory ability (Eriksen & Eriksen, 1974). To our knowledge, no previous study has used a flanker task to assess inhibitory ability in individuals with ASD.

Unlike a Stroop or flanker task, a go/no-go task requires an individual to withhold a response entirely as opposed to generating an alternate response (Drewe, 1975). In a typical go/no-go task, a series of visual stimuli (e.g., letters) is presented. Participants are instructed to respond to a majority of the stimuli (e.g., all letters except *A*) but withhold their response to a small subset of stimuli (e.g., the letter *A*). Given that a response is required on a large majority of trials (e.g., 75%), the tendency to respond must be inhibited when a no-go stimulus is presented. Ozonoff et al. (1994) found that children with ASD performed more poorly than control children on a go/no-go task. In their study, however, go and no-go stimuli occurred with equal frequency (50%–50%). They created a prepotent response tendency by having participants initially respond to a stimulus utilizing one stimulus-response mapping (e.g., respond to the letter *A* but don't respond to the letter *B*) and then later switching the stimulus-response mapping (e.g., now respond to the letter *B* and not to the letter *A*). The poor performance of children with ASD on Ozonoff et al.'s go/no-go task may have been related to difficulties in switching stimulus-response mappings (i.e., cognitive flexibility) rather than inhibitory control (Ozonoff & Strayer, 1997). A more recent study of go/no-go performance in adults with ASD by Raymaekers, van der Meere, and Roeyers (2004) avoided this potential confound. The stimulus-response mapping utilized in their go/no-go task remained constant throughout the experiment. A strong response tendency was created by manipulating the frequency of go (i.e., 80%) and no-go (i.e., 20%) stimuli. They found that individuals with ASD performed more poorly than controls when the presentation rate of the stimuli was fast (i.e., every 1 or 2 s) but not when it was slower (i.e., every 6 s).

Raymaekers et al. (2004) interpreted their findings as evidence of an inability to modulate arousal (related to the rate of stimulus presentation) rather than an inhibitory impairment. Of note, however, the slow presentation condition in the Raymeakers et al. study consisted of only 100 stimuli and was administered first to all participants. Given that the ratio of go trials to no-go trials in a go/no-go task is learned implicitly by participants through task experience, the prepotent response tendency (i.e., likelihood of responding on a no-go trial) might be expected to increase as a participant's experience with the task increases. It therefore was possible that the inhibitory demands in the Raymaekers et al. study were greater in the later conditions (i.e., medium and fast presentation rate). As such, the finding of ASD-related impairment in these conditions may have been related to the strength of the response tendency that needed to be inhibited rather than to the rate of stimulus presentation. The go/no-go task utilized in the present investigation consisted of 200 experimental trials thus allowing sufficient time for a strong response tendency to emerge. In addition, whereas the Raymaekers et al. study focused on high functioning adults with autism, the present study investigated go/no-go performance in children with ASD.

As noted above, the aim of the present investigation was to provide additional evidence regarding the state of inhibitory control in children with ASD. To accomplish this, we administered three inhibitory tasks to children with ASD and to children with no history of ASD. Non-inhibitory (i.e., neutral) conditions were included in order to control for individual differences in processing speed and to ensure that group-related findings were not solely attributable to slowed processing speed in children with ASD. Siblings of children with ASD and typically developing non-sibling children comprised our comparison group.

Method

Participants

Eighteen children (16 males, 2 females) with autism spectrum disorder (ASD) who ranged from 6 to 12 years of age (M = 8.2 years, SD = 1.6 years) participated. Fourteen of the children were diagnosed with autistic disorder, two children were diagnosed with Asperger's disorder, and the remaining two children were diagnosed with pervasive developmental disorder, not otherwise specified. All of the children were between the ages of 2 and 5 years at the time of initial diagnosis. The initial diagnosis was made by a psychologist, neurologist, or other qualified health professional based on DSM-IV (American Psychiatric Association, 1994) criteria. Potential participants were recruited from the St. Louis community via word-of-mouth and an announcement in a Missouri Families for Effective Autism Treatment newsletter. Individuals with severe cognitive impairment and individuals with histories of learning disorders or major medical disorders unrelated to autism were excluded. Potential participants also were screened for visuoperceptual disorders (e.g., color-blindness).

Twenty-three biological siblings (12 males, 11 females) of children with ASD who ranged from 6 to 15 years of age (M = 10.2 years, SD = 2.1 years) comprised a sibling control group. A non-sibling control group consisted of 25 typically developing children (11 males, 14 females) who ranged from 7 to 18 years of age (M = 11.3 years, SD = 3.4 years). None of the children in either control group had a history of ASD or other neurological compromise. Performance of the non-sibling controls has been reported previously (Christ, Steiner, Grange, Abrams, & White, in press). Non-sibling control children were recruited via word-of-mouth from the St. Louis, Missouri and Portland, Oregon communities.

An age-standardized estimate of overall intellectual ability was obtained using the Wechsler Abbreviated Scale of Intelligence (Psychological Corporation, 1999). The estimated full-scale IQ was significantly lower for the ASD group (M = 88.4, SD = 16.3) than for the sibling control group (M = 116.7, SD = 16.5) or the non-sibling control group (M = 107.7, SD = 10.6).

Materials and Procedure

All tasks were administered in a small, quiet room with sufficient overhead lighting. The apparatus and procedure for each task were identical to those described previously (Christ et al., in press; Christ, White, Brunstrom, & Abrams, 2003). Reaction time (RT) and error rate were recorded for each condition of each computer task. The order of task administration was varied randomly across participants.

Stroop Card Task

The three conditions of Golden's (1978) Stroop Color and Word Test were administered in the following order. In the first condition (word control), children were shown a page on which color names (e.g., ''Red'') were printed in black ink. They were asked to read the words aloud as quickly as possible. In the second condition (color control), children were shown a page on which clusters of Xs in colored ink were printed and were asked to name the ink color as quickly as possible. In the inhibitory condition, children were shown a page on which color names were printed in incongruent ink colors (e.g., the word ''Red'' printed in blue ink). They were asked to name the ink color, requiring inhibition of the prepotent reading response. For all three conditions, the number of items completed in 45 s was recorded. If an incorrect response was given to an item, the child was prompted to respond correctly before continuing.

Stroop Computer Task

Children were seated in front of a computer monitor and a panel containing three large response buttons. One of the buttons was red, another blue, and another green. Three experimental conditions were administered: congruent, incongruent, and neutral. The stimuli employed in each condition were a subset of those used previously (Carter, Robertson, & Nordahl, 1992). On congruent trials, one of three stimulus words (i.e., RED, BLUE, or GREEN) was presented in its associated color (e.g., the word RED presented in red) at

the center of the monitor. On incongruent (i.e., inhibitory) trials, one of the three-color words was presented in an incongruent color (e.g., the word BLUE presented in red). On neutral trials, one of three stimulus words (i.e., DOG, BEAR, or TIGER) was presented in blue, red, or green.

The stimuli subtended approximately 2° vertically and 5° to 7° horizontally. Children were asked to press the response button indicating the color in which each stimulus was presented. For each trial, the stimulus remained on the display until a response was made or until 3,000 ms elapsed. After an intertrial interval of 2,000 ms, a new trial was presented.

Three types of errors were possible. If a child responded in less than 100 ms after the presentation of a stimulus, a brief tone followed by the visual message ''Early response'' was presented. If a child failed to respond within 3,000 ms, a tone and ''Too slow'' were presented. If a child responded by pressing the incorrect button, a tone and ''Wrong response'' were presented.

Following 20 practice trials, each child completed 108 experimental trials, with 36 trials in each of the three conditions. Trial types were intermixed randomly. Presentation was balanced such that all possible stimulus–color pairings (e.g., RED presented in blue, RED presented in green, etc.) were equally likely to occur. At intervals of 27 trials, children were offered a break.

Flanker Task

Children were seated in front of a computer monitor and two large response buttons. Three experimental conditions were administered: compatible, incompatible, and neutral. The stimuli employed were a subset of those used previously (Enns & Akhtar, 1989). Each trial began with the presentation of a central fixation dot. After 300 ms, the dot brightened for 500 ms then disappeared. Following a delay of 300 ms, one of four target stimuli (□, O, +, X) subtending 1° was displayed centrally. Children were asked to respond as quickly as possible to the target identity. Half of the children pressed the left button when the target was a □ or O and pressed the right button when the target was a + or X. The stimulus-response mapping was reversed for the remaining children.

On compatible trials, the target was closely flanked (<.5°) to the left and right by a stimulus mapped to the same response button (e.g., □O□). On incompatible (i.e., inhibitory) trials, the target was flanked by a stimulus mapped to the alternative response button (e.g., +O+). On neutral trials, the flankers were one of two stimuli (Δ or *), neither of which mapped to a response button. For each trial, stimuli remained on the monitor until a response was made or until 3,000 ms elapsed. After an intertrial interval of 2,000 ms, a new trial was presented.

If a child responded in less than 100 ms after presentation of the target, a brief tone followed by the message ''Early response'' was presented. If a child failed to respond within 3,000 ms, a tone and ''Too slow'' were presented. If a child responded by pressing the incorrect button, a tone and ''Wrong response'' were presented.

Children completed two practice blocks of 20 trials each. In the first block, target stimuli were presented without flankers. In the second block, practice trials were identical to experimental trials. After practice, children completed 96 experimental trials, with 32 trials in each of the three conditions. Trial types were intermixed randomly. Presentation was balanced such that all possible stimulus-flanker pairings were equally likely to occur. At intervals of 24 trials, children were offered a break.

Go/No-go Task

Children were seated in front of a computer monitor and a large response button. Two experimental conditions were administered: go and no-go. On each trial, one of four stimuli (◇, □, Δ, O) subtending approximately 6° vertically and horizontally was centrally displayed. Prior to beginning the task, one of the stimuli was designated as the non-target. Children were asked to press the response button as quickly as possible when any stimulus appeared except the non-target (go trials). Children were instructed to make no response when the non-target appeared (no-go trials). After an intertrial interval of 2,000 ms, a new trial was presented.

If a child responded in less than 100 ms after the presentation of a target, a brief tone followed by the visual message ''Early response'' was presented. If a child failed to respond within 1,500 ms, a tone and ''Too slow'' were presented. If a child responded on a no-go trial, a tone and ''No response needed'' were presented.

Following 20 practice trials, children completed 200 experimental trials. Presentation was balanced such that each stimulus was equally likely to occur; non-targets were presented on a minority (25%) of trials. The trial types were intermixed randomly. The stimulus designated as the non-target was counterbalanced across children. At intervals of 40 trials, children were offered a break.

Results

Past studies investigating potential differences in performance on measures of executive abilities between siblings of children with autism and children from unaffected families have found mixed results (e.g., Hughes, Plumet, & Leboyer, 1999; Ozonoff, Rogers, Farnham, & Pennington, 1993). Of particular interest, Ozonoff et al. (1993) found that the performance of siblings of children with autism was comparable to that of siblings of children with learning disabilities on the Wisconsin Card Sorting Test, a test of set-shifting, working memory, and inhibitory control.

Within this context, the sibling and non-sibling control groups in the present study performed comparably on all measures of processing speed and inhibitory control. The two groups were similar to each other in terms of age, gender, and overall intellectual ability as well. To bolster statistical power and maximize our ability to detect ASD-related differences in inhibitory performance, we collapsed across these control groups to form a single comparison group for all remaining analyses.

The ASD group differed from the combined comparison group in terms of age, $t(64) = 3.59$, $p < .05$, gender, Mann–Whitney $U = 255.0$, $p < .05$, and estimated IQ, $t(64) = 5.73$, $p < .05$. Whereas age and IQ were significantly correlated with inhibitory performance, gender was not. As a result, gender was excluded from further analyses. Overall, the ASD group also responded more slowly (Mean RT across tasks: ASD = 929 ms, control = 667 ms; $t(64) = 7.12$, $p < .05$) and made more errors (mean error rate across tasks: ASD = 11.9%, control = 5.4%; $t(64) = 5.77$, $p < .05$) on the computer tasks than the comparison group.

A hierarchical regression approach was used to control for group differences on non-inhibitory variables such as age, overall intellectual ability, and processing speed. RT in the inhibitory condition served as the dependent variable. Age, estimated IQ, and neutral condition RT (i.e., a measure of processing speed) were included in the first step of the statistical model. Group (ASD and control) was then entered into the model. By utilizing this approach, we are able to partial out all variability in inhibitory performance related to age, IQ, and processing speed. The portion of the remaining variance that is attributable to group membership is then identified.

Analyses of error rates were conducted in a similar fashion with age, IQ, and error rate in the neutral condition (i.e., a measure of general error rate) being entered in the first step of the model. Age, IQ, and scores from the word and color control conditions (i.e., number of items completed for each condition—measures of reading fluency and processing speed, respectively) were entered in the first step for the Stroop card task analysis.

For the computer tasks, the trials on which an error occurred were excluded from the RT analyses. For the flanker task, three children from the ASD group were unable to perform the task successfully. For the go/no-go task, two were unable to perform the task. All of the children from both groups were able to complete both Stroop tasks. The analyses for both Stroop tasks are confined to data from children seven years of age or older who also demonstrated fluent reading abilities (i.e., completed the word control condition of the Stroop card task). Previous work suggests that, by this age, children have developed reading abilities sufficient to generate substantial Stroop interference effects (Comalli, Wapner, & Werner, 1962; Schiller, 1966). This criterion resulted in the exclusion of three younger children from the control group and two children from the ASD group.

Median RTs and error rates for each inhibitory task are listed in Table 1. The results of the regression analyses are summarized in Table 2. For each inhibitory variable, the overall proportion of variance (R^2) explained by the model as well as the squared partial correlation (pr^2) for each independent variable (i.e., the proportion of variance not associated with other variables that *is* associated with the given variable) are listed. Of most interest, the pr^2 for the group variable reflects the proportion of variance in inhibitory performance attributable to group (ASD and control) after accounting for variance related to differences in age, IQ, and processing speed. For the findings reported below, one-tailed independent samples t tests were used.

Stroop Tasks

The performance of children with ASD on the inhibitory component of the Stroop computer task was comparable to that of control children. This was true for both RT and error rate, after accounting for individual differences in age, IQ, processing speed, and general error rate. In addition, the two groups performed equivalently on the incongruent (inhibitory) condition of the Stroop card task.

Flanker Task

Children with ASD responded significantly more slowly in the inhibition condition than controls, $t(58) = 1.82$, $p < .05$. Group membership accounted

Table 1 Means and standard deviations for unadjusted median RT (ms) and error rates (%) in each experimental task as a function of group

Dependent variable	Control					ASD				
	N	RT/score		Error rate		*N*	RT/score		Error rate	
		M	*SD*	*M*	*SD*		*M*	*SD*	*M*	*SD*
Stroop computer task	16					45				
Neutral trials		800	167	.9	1.4		1033	167	6.6	5.3
Inhibitory trials		883	224	2.2	2.8		1245	298	10.8	8.5
Stroop card task	16					45				
Number of word control correct		78	16				47	13		
Number of color control correct		54	15				36	9		
Number of incongruent correct		31	10				20	5		
Flanker task	15					48				
Neutral trials		729	195	7.1	6.3		1125	226	11.5	12.5
Inhibitory trials		751	220	9.3	8.2		1234*	272	15.2	13.9
Go/no-go task	16					48				
Go trials		434	67.4	2.7	2.9		497	65.9	9.9*	5.4
No-go trials				24.0	14.2				38.0	15.4

* Effect of group, $p < .05$

for 5.4% of the variance in inhibition RT after removing the contributions of age, IQ, and processing speed. The groups did not differ significantly in error rates.

Go/No-go Task

Unlike the Stroop and flanker tasks, the go/no-go task did not include a measure of baseline performance. As a result, the average RT across the neutral conditions of the Stroop and flanker tasks was computed for each participant, and the resulting variable was used as a measure of general processing speed in the go/no-go RT analyses. A general error rate was similarly computed from the Stroop and flanker neutral conditions and used in the go/no-go error analyses.

The two groups performed comparably in terms of go-trial RT and no-go-trial error rate; however, children with ASD made significantly more errors than controls on go trials, $t(59) = 3.55$, $p < .05$. Post-hoc analyses revealed that this was true in terms of both too fast errors, $t(59) = 3.31$, $p < .05$, and too slow errors, $t(59) = 2.47$, $p < .05$. Group membership accounted for 17.6% of the variance in go-trial error rate after removing the contributions of age, IQ, and general error rate.

Supplementary Age-matched Analyses

To confirm the validity of our statistical approach and results, we identified a subset of the control group who matched the ASD group in terms of chronological age.

Table 2 Hierarchical regression analysis predicting inhibitory performance from control variables and group membership

Dependent variable	Step 1				Step 2	
	R^2	Processing speed (pr^2)	Age (pr^2)	Full scale IQ (pr^2)	R^2	Group (pr^2)
Stroop computer task						
Median RT on inhibitory trials	.884*	.80*	.00	.00	.884	.00
Error rate on inhibitory trials	.655*	.52*	.15*	.00	.661	.02
Stroop card task						
Number of incongruent correct	.698*	.01, .01[a]	.33*	.16*	.703	.02
Flanker task						
Median RT on inhibitory trials	.920*	.85*	.01	.00	.924	.05*
Error rate on inhibitory trials	.533*	.52*	.00	.04	.533	.00
Go/no-go task						
Median RT on go trials	.415*	.16*	.04	.01	.418	.00
Error rate on go trials	.359*	.13*	.12*	.15*	.472*	.18*
Error rate on no-go trials	.296*	.09*	.16*	.03	.303	.01

* $p < .05$

[a] Partial correlations for # correct for word and color conditions shown separately

The statistical analyses then were repeated with data from these two groups (with the exception that age was not entered as a control variable). The results were identical to those detailed above—children with ASD performed more poorly than the controls only on the flanker and go/no-go tasks.

There was not sufficient overlap between the groups in terms of IQ to allow a similar approach with this factor. As can be seen in Table 2, however, IQ explained very little variance in inhibitory performance above and beyond that already explained by chronological age and processing speed. This finding is consistent with several previous studies using similar inhibitory tasks that have failed to find a strong relationship between general intellect and inhibitory performance in school-aged children (Christ et al., 2003; Oosterlaan & Sergeant, 1996; Rubia et al., 1999).

Discussion

Children with ASD performed more poorly than control children on some but not all of the inhibitory tasks administered in the present study. Specifically, children with ASD performed comparably to controls on computer and card versions of the Stroop paradigm. Their performance was impaired, however, on a go/no-go task and a flanker interference task.

The present Stroop results are consistent with previous studies by Eskes et al. (1990) and Ozonoff and Jensen (1999), which also failed to find evidence of ASD-related impairment on a card version of the Stroop paradigm. Our results extend these findings by demonstrating that children with ASD perform equivalently to controls on a single-trial, computer-administered Stroop task, as well.

In the current go/no-go task, children with ASD made significantly more errors on go trials than the comparison group. This continued to be true even after accounting for group differences in age, IQ, and general error rate. It remains unclear whether this finding is due to an impairment in inhibitory control or, alternatively, to difficulty in sustaining attention. Typically, deficient inhibitory control leads to an increased error rate on no-go trials (i.e., how frequently a participant responds to a stimulus when they should not; Casey et al., 1997). In the present study, however, the no-go error rate of children with ASD was equivalent to that of the comparison group.

Upon closer inspection, it was found that the increased go-trial error rate in children with ASD was the result of high rates of both too slow errors and too fast errors. This pattern of errors appears to be indicative of high response variability. Consistent with this interpretation, the within-subjects variability in RT for correct go-trials was substantially higher for the ASD group (mean $\sigma = 176.8$) than for the comparison group (mean $\sigma = 122.3$), $t(62) = 5.07$, $p < .05$. Increased response variability frequently is interpreted as evidence of difficulties with sustained attention (Schatz, Weimer, & Trauner, 2002).

Any attempts at this time, however, to attribute the observed group differences in go-trial error rates to either an impairment in inhibitory control or an impairment in sustained attention would be speculative at best. Additional research is needed to clarify the nature of this finding. Along these lines, it would be informative in the future to compare performance on a go/no-go task with that on a separate measure of sustained attention with children with ASD.

In contrast to the findings from the Stroop and go/no-go tasks, an inhibitory impairment for children with ASD clearly was apparent on the flanker task. Children with ASD responded more slowly on inhibitory (i.e., incompatible) trials than their control counterparts. This difference cannot be attributed to impairments in lower-level cognitive processes since the visual processing demands were equivalent for the inhibitory and neutral conditions, with stimuli differing only in terms of the identity of the flankers. Moreover, the presentation of the neutral and inhibitory trials was intermixed such that deficiencies in non-inhibitory abilities (e.g., sustained attention) should affect performance in the neutral and inhibition conditions equally. As a result, the poorer performance in the inhibitory condition by children with ASD compared to control children likely reflects a deficiency in inhibitory ability.

Although comparable with past studies of ASD, the size of the clinical group in the present investigation was small (i.e., 18 children). In such cases, statistical power (or lack thereof) is always a concern. The present failure to identify group-related differences in Stroop performance, however, is likely unrelated to statistical power. The effect of group (ASD and control) did not approach statistical significance for either the computer or card Stroop tasks, $t(56) < 1.1$, $pr^2 < .03$, in all instances. Regarding the flanker and go/no-go tasks, a potential lack of statistical power is a concern only when there is a failure to reject the null hypothesis (i.e., performance of the ASD group is comparable to that of the control group; Hayes, 1994). Given that significant group differences were observed on the flanker and go/no-go tasks ($pr^2 = .05$ and $pr^2 = .18$, respectively), statistical power would not appear to be an issue.

In the present study, the children who comprised the comparison group were either biological siblings of children with ASD or typically developing children with socioeconomic backgrounds similar to the children with ASD. As a result, factors related to home environment were likely comparable across the ASD group and the comparison group. The ASD and comparison groups, however, did differ significantly in terms of chronological age and overall intellectual ability. To address this issue, we adopted a statistical approach that allowed us to partial out the variability in inhibitory performance related to these factors and thereby focus on the variability attributable to group membership (ASD and control). An alternate approach would be to recruit control children who match the ASD group on one of these variables; however, such an approach is likely to result in the groups being mismatched on another factor (e.g., home environment). Jarrold and Brock (2004) recently discussed the advantages of a statistical approach such as ours as compared to a reliance on only matching strategies. Further, it should be recalled that a secondary analysis in which we used age-matched subgroups of children provided support for the validity of our approach. In the future, we hope to increase our participant pool thus allowing for similar subgroup matching on the basis of other factors, such as intellectual ability and processing speed.

As noted earlier, whereas a handful of studies have found evidence of inhibitory impairment in individuals with ASD (e.g., Geurts et al., 2004; Minshew et al., 1999; Ozonoff et al., 1994), others have failed to find such differences (e.g., Eskes et al., 1990; Ozonoff & Jensen, 1999; Ozonoff & Strayer, 1997). One possible explanation for these disparate findings is that the cohorts of individuals with ASD recruited across studies varied in some important way. Another possibility is that the various inhibitory tasks (e.g., Stroop, go/no-go) used in different studies were assessing different aspects of inhibitory ability. Since most past studies have utilized only one task to assess inhibitory control, it is impossible to confidently distinguish between these two possibilities.

The present finding of ASD-related inhibitory impairment on the flanker task but not on the two Stroop tasks cannot be explained in terms of cohort differences. The present pattern of results, however, is consistent with the idea that the Stroop and flanker tasks are measuring different aspects of inhibitory control, and specific aspects of inhibitory control may be impaired in children with ASD. We are not the first to suggest such a distinction.

For example, Casey and colleagues (Casey, Durston, & Fossella, 2001; Casey, Tottenham, & Fossella, 2002) have postulated that inhibitory control can be divided into subcomponents, and that each subcomponent maps onto a different stage of cognitive processing: stimulus selection, response selection, and response execution. Building on previous work describing five anatomically distinct neural circuits involving the frontal cortex, basal ganglia, and thalamus (Alexander, DeLong, & Strick, 1986; Cummings, 1995), Casey et al. (2001; 2002) proposed that each inhibitory subcomponent is subserved by a different frontostriatal circuit.

The three frontostriatal circuits of particular relevance to the present discussion are those involving the dorsolateral prefrontal cortex, lateral orbital frontal cortex, and anterior cingulate/medial orbital cortex. These three circuits are hypothesized to be involved in inhibitory control at the cognitive stages of stimulus selection, response selection, and response execution, respectively.

Extending Casey's model to results from the current study, it is possible that the integrity of some but not all neural circuits subserving inhibitory control are compromised in children with ASD. Attributing the present pattern of intact and impaired performance across inhibitory tasks to disruptions in specific PFC circuits, however, is speculative at best for a number of reasons. First, there is a lack of detail regarding the neuroanatomical and neurophysiological sequelae experienced by children with ASD. Second, it is likely that inhibitory control is required at more than one of the aforementioned cognitive stages during the inhibitory tasks used in the present study, and there is overlap in cognitive stages across inhibitory tasks. For example, it has been suggested that the flanker and Stroop tasks both require inhibitory control at the level of response selection (flanker: Eriksen, 1995; Stroop: MacLeod, 1991). Future studies utilizing neuroimaging techniques may allow us to better understand the interplay between the neurological compromise experienced by children with ASD and their inhibitory performance.

Finally, the present study speaks to the importance of utilizing multiple measures when assessing a "single" ability or cognitive domain (for additional discussion of this topic, see Carlson, 2003). The need for multiple methods is especially critical in light of the aforementioned efforts to distinguish ASD from other executive-related disorders based on the pattern of sparing and impairment seen across measures of executive ability (e.g., Ozonoff & Jensen, 1999). For example, ASD researchers relying on a lone Stroop task to evaluate inhibitory control would come to a very different conclusion (i.e., inhibitory control is

intact in children with ASD) than those using a flanker task (i.e., inhibitory control is impaired in children with ASD). By utilizing several measures of inhibitory control, the present study was able to elucidate our understanding of ASD and inhibitory control while avoiding this potential pitfall.

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