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Executive functions in children with Autism Spectrum Disorders

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ABSTRACT

Executive dysfunction is a characteristic impairment of individuals with Autism Spectrum Disorders (ASD). However whether such deficits are related to autism per se, or to associated intellectual disability is unclear. This paper examines executive functions in a group of children with ASD ($N = 54$, all IQ$\geqslant$70) in relation to a typically developing control group individually matched on the basis of age, gender, IQ and vocabulary. Significant impairments in the inhibition of prepotent responses (Stroop, Junior Hayling Test) and planning (Tower of London) were reported for children with ASD, with preserved performance for mental flexibility (Wisconsin Card Sorting Task) and generativity (Verbal Fluency). Atypical age-related patterns of performance were reported on tasks tapping response inhibition and self-monitoring for children with ASD compared to controls. The disparity between these and previous research findings are discussed. A multidimensional notion of executive functions is proposed, with difficulties in planning, the inhibition of prepotent responses and self-monitoring reflecting characteristic features of ASD that are independent of IQ and verbal ability, and relatively stable across the childhood years.

1. Introduction

The concept of 'executive function' refers to the higher order control processes necessary to guide behaviour in a constantly changing environment (Jurado & Rosselli, 2007). The concept includes abilities such as planning, working memory, mental flexibility, response initiation, response inhibition, impulse control and monitoring of action (Roberts, Robbins, & Weiskrantz, 1998; Stuss & Knight, 2002). Behavioural and neuropsychological studies originally linked executive functions to the frontal lobes, in particular the pre-frontal cortex (Baddeley & Wilson, 1988; Stuss & Benson, 1986). However, more recent neuroimaging studies have shown that executive functions are associated with different regions of the frontal lobes, with links between frontal and posterior areas, as well as subcortical and thalamic pathways (Monchi, Petrides, Strafella, Worsley, & Doyon, 2006; Stuss & Alexander, 2000; Stuss et al., 2002).

Executive dysfunction has been linked to a number of developmental disorders, including Autism Spectrum Disorder (ASD) (see Russell, 1997). Behavioural similarities between patients with frontal lobe lesions and individuals with ASD led to the notion that some of the everyday social and non-social behaviours seen in individuals with ASD may reflect specific executive dysfunction (Ozonoff, Pennington, & Rogers, 1991). The behaviours proposed to be accounted for by the theory of executive dysfunction include; a need for sameness, a strong liking for repetitive behaviours, lack of impulse control, difficulty initiating new non-routine actions and difficulty switching between tasks (Hill, 2004; Rajendran & Mitchell, 2007). These non-social behaviours comprise strengths as well as weaknesses for individuals with ASD, and they are not successfully accounted for by the theory of mind deficit hypothesis (Happé, 1994), weak central coherence accounts (Frith, 1989, 2003) or the extreme male brain theory (Baron-Cohen, 2002).

Executive dysfunction in ASD has been widely investigated. In a review of the ASD literature, Hill (2004) divided studies into the executive domains of; planning, mental flexibility, inhibition, generativity and self-monitoring. Difficulties have been reported in each of these domains for individuals with ASD (e.g. Hill & Bird, 2006; Hughes & Russell, 1993; Ozonoff et al., 2004; Rumsey & Hamburger, 1988; Russell, Jarrold, & Hood, 1999). However, preserved performance has also been documented (e.g. Boucher, 1988; Hughes, Russell, & Robbins, 1994; Ozonoff & Jensen, 1999; Russell & Hill, 2001). Hill (2004) attributed these inconsistencies to methodological differences, such as task selection, participant matching and ability level. In particular, the inclusion of participants with cognitive impairments means that the extent to which executive difficulties reflect autistic symptomology or intellectual disability is unclear. Hill (2004) proposed there is a need for better controlled studies to establish whether executive deficits are causally related to autistic symptomology. To address these issues, this paper reports findings from a sample of children with ASD, whose

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IQ's fall within the normal range, in relation to typically developing age, IQ and vocabulary matched controls, for the executive domains of planning, mental flexibility, response inhibition and generativity, and self-monitoring.

1.1. Planning

Planning is a cognitive skill that requires constant monitoring, evaluation and updating of actions (Hill, 2004). The Tower of Hanoi (ToH) or the Tower of London (ToL) tasks are often used to assess planning and problem solving skills. On these tasks, participants must move beads from a prearranged sequence to match a goal state determined by the examiner. Children with ASD, with IQ scores at the lower end of the normal range, have been reported to be significantly impaired on these tasks compared to age and/or IQ matched controls (typically developing, intellectually impaired or other groups with other developmental disorders, such as ADHD, Tourette syndrome and dyslexia; Geurts, Verte, Oosterlann, Roeyers, & Sergeant, 2004; Hughes et al., 1994; Ozonoff & Jensen, 1999; Ozonoff & McEvoy, 1994; Ozonoff et al., 1991). Impaired planning of underhand reaches on the Luria bar task (Hughes, 1996) and slowed performance on the Milner mazes (Milner, 1965; Prior & Hoffman, 1990) has also been reported for children with ASD.

In contrast, on a computerised version of the ToH/ToL tasks, the Stockings of Cambridge task (SoC), Happé, Booth, Charlton, and Hughes (2006) reported normal performance for children with ASD who had IQ's above 70. They also reported a significant reduction in the number of extra moves made by older children (11–16 years) to complete problems compared with younger children (8–10 years). This suggests that planning deficits may be related to level of general intellectual functioning and maturation. Mari, Castiello, Marks, Marraffa, and Prior (2003) also reported that impaired planning ability on a kinematic reach-to-grasp task was related to level of IQ rather than to autism. However, impaired planning on the Trail Making Test (Army Individual Test Battery, 1944; Rumsey & Hamburger, 1988) has been reported for men with ASD whose IQ's fell within the normal range. The computerised and standard version of the ToH/ToL task may also not be equivalent. Thus, is it unclear whether discrete cognitive task demands or level of intellectual functioning contribute to the preserved performance reported by Happé et al. (2006).

1.2. Mental flexibility

Mental flexibility refers to the ability to shift to a different thought or action in response to situational changes. The Wisconsin Card Sorting Task (WCST) is a classic test of mental flexibility that requires participants to sort cards according to one of three possible rules (colour, shape or number). Difficulty in shifting to a new sorting procedure is typically taken as the primary index of executive dysfunction (Hill, 2004). Individuals with autism have been reported to be highly perseverative on this task compared to typically developing (TD) controls and controls with other developmental disorders, such as, attention deficit hyper-activity disorder (ADHD), language disorder, Tourette syndrome and dyslexia (Geurts et al., 2004; Liss et al., 2001; Ozonoff & Jensen, 1999; Ozonoff et al., 1991; Rumsey, 1985). Similarly, impaired performance has been reported on the intradimensional–extradimensional shift task of the Cambridge Neuropsychological Test Automated Battery (Cambridge Cognition, 1996) for individuals with ASD (Hughes et al., 1994; Ozonoff et al., 2004).

However, Liss et al. (2001) reported no significant difference in perseverative errors on the WCST between children with autism and children with developmental language disorder once verbal IQ was controlled for. This suggests that perseverative tendencies may be related to verbal ability. Normal perseverative performance has also been reported for individuals with autism who have IQ's within the normal range (i.e. above 70; Ozonoff, 1995), though this has not been found by all (Minshew, Goldstein, Muenz, & Payton, 1992). Ozonoff (1995) also reported attenuated rates of perseveration for children with ASD on a computerised version of the WCST compared to the traditional card version, which may reflect reduced verbal and social task demands. In addition, multiple component skills are required for successful performance on the WCST (e.g., generation of a sorting rule, working memory to hold the sorting principle, use of feedback to inhibit prepotent responding, the ability to shift set). Thus, although many studies have reported difficulties in mental flexibility for individuals with ASD, poor performance may be confounded by level of general intellectual functioning, verbal ability and task demands.

1.3. Response inhibition

Response inhibition is the ability to suppress irrelevant or interfering information or impulses. The Stroop (Stroop, 1935) is a classic task of response inhibition that requires participants to name the colour that words are written in, whilst ignoring the word representing colour itself (e.g. "red"/"blue"). Regardless of level of intellectual functioning, interference effects for children and adults with ASD are not reported to differ significantly from controls on traditional card versions of this task (Hill & Bird, 2006; Ozonoff & Jensen, 1999; Russell et al., 1999). This is in contrast to children with ADHD and Tourette syndrome for whom inhibitory performance on this task is reported as impaired (Ozonoff & Jensen, 1999). Typical interference effects have also been reported for children with ASD, with IQ's within the normal range for the Go/No-Go task, Stop-Signal task and negative priming tasks (Ozonoff & Strayer, 1997; Ozonoff, Strayer, McMahon, & Filloux, 1994; Schmitz et al., 2005). Performance on computerised versions of the Stroop have not yet been investigated for children with ASD.

Impaired response inhibition has, however, been reported on the Windows Task, and variations of this task, for children with ASD (Bíro & Russell, 2001; Hughes & Russell, 1993; Russell, Hala, & Hill, 2003; Russell, Mauthner, Sharpe, & Tidswell, 1991). On these tasks, in order to win a desired object (chocolate) visible in a box, children are required to inhibit the prepotent response of pointing to the box with the chocolate in it and instead point to an empty box beside it. Consistently poor performance on these tasks indicates a difficulty inhibiting prepotent responding.

The Hayling test (Burgess & Shallice, 1997) is another measure of prepotent response inhibition. In the first part of this test participants are required to complete the last word of a sentence as quickly as possible, whilst in the second part they are required to complete the sentence using a word that does not fit the context. Hill and Bird (2006) reported impaired performance (increased response latencies) on this test for adults with ASD. They proposed that poor performance reflected a generative deficit rather than an executive impairment in inhibition or strategy formation; however strategy formation was not directly assessed. Performance on this task has not yet been reported for children with ASD. It is therefore unknown whether performance is impaired for children with ASD and if so whether poor performance reflects an impairment in the inhibition of prepotent responses, strategy formation, generativity or the arbitrary nature of the rules.

1.4. Generativity and self-monitoring

Generativity is the ability to generate novel ideas and behaviours spontaneously (Turner, 1997). Tests of Verbal Fluency are typically used to assess generativity. These tasks require participants to produce as many words as possible within a specified time in response to either a phonemic (e.g. the letter F) or semantic cue (e.g. the category of animals). Impaired performance has been reported for individuals with autism in relation to age and ability matched controls (Minshew et al., 1992; Rumsey & Hamburger, 1988; Turner, 1999), though this has not been found by all (Boucher, 1988; Scott & Baron-Cohen, 1996). A generative deficit has been proposed to account for impaired performance on measures of response inhibition (Hill & Bird, 2006). Generativity may therefore contribute to the pattern of performance reported for children with ASD in other executive domains.

Self-monitoring is the ability to monitor one's own thoughts and actions (Hill, 2004). Specific tests designed to assess this executive domain are not well established and they have generally failed to find any performance differences in ASD (Hill & Russell, 2002). Impairments in self-monitoring have only been reported on a post hoc basis, for example error correction, avoidance and memory for actions (Hughes, 1996; Russell & Jarrold, 1998, 1999). Monitoring one's verbal output is required on tests of Verbal Fluency to prevent item repetition. A deficit in self-monitoring might therefore be apparent in perseverative responses on these fluency tasks, again this has not yet been reported for individuals with ASD.

1.5. Research aims

The aim of the present study was to provide information relevant to identifying the nature of executive functions in children with ASD. As discussed above, performance was assessed for mental flexibility, planning, inhibition and generativity. Children with ASD were individually matched to TD controls on the basis of age, IQ, receptive vocabulary and gender. To ensure that performance differences reflected autistic symptomology and not level of intellectual functioning, performance was assessed for children whose IQ's fell within the normal range. Age-related differences in performance were also investigated. The specific research questions to be addressed by the study were:

(1) Do children with ASD exhibit executive impairments in planning, mental flexibility, inhibition or generativity?
(2) Do children with ASD exhibit typical age-related differences in executive performance?
(3) To what extent does intellectual disability influence executive functioning in children with ASD?

2. Method

2.1. Participants

A total of 108 children from England and Scotland participated in the study. Criteria for inclusion were: age 8;0–17;0 years; Full Scale IQ (FSIQ) 70–130 (i.e. within two-standard deviations of the mean); English as a first language. Children with ASD were recruited through various support groups associated with the National Autistic Society, Mainstream Schools and Educational Institutes specialised in teaching individuals with ASD. Control participants were recruited from a variety of Mainstream Primary and Secondary Schools. Written parental consent and informed participant consent was obtained prior to testing. Ethics permission was granted by both the University of St. Andrews and Goldsmith College ethics committees.

The ASD group comprised 54 children with a clinical diagnosis of Asperger Syndrome or High Functioning Autism. In each case, diagnosis was based on established criteria (DSM-IV; APA, 1994) and was made by a multidisciplinary diagnostic team including a Psychiatrist or Clinical Psychologist. Clinical diagnosis was reconfirmed on the basis of scores on the Social Communication Questionnaire (SCQ) (Rutter, Bailey, & Lord, 2003), a 40-item parent checklist derived from the Autism Diagnostic Interview – Revised (ADI – R) (Lord, Rutter, & Le Couteur, 1994). A high level of agreement has been reported between scores obtained on the SCQ and ADI – R (Berument, Rutter, Lord, Pickles, & Bailey, 1999). The SCQ has established validity for a diagnosis of autism (Berument et al., 1999; Chandler et al., 2007), with an SCQ score above a cut-off of 12 recommended for research purposes (Lee, David, Rusyniak, Landa, & Newschaffer, 2007). This cut-off was therefore used in the current study ($M = 24.4$, SD = 6.73). The TD control group comprised 54 children randomly selected on the basis of date of birth. To ensure the control group did not include children with developmental disorder, children were excluded if they had a known neurological abnormality, diagnosed learning difficulties or a history of special needs. Control participants were individually matched to ASD participants on the basis of age, full scale IQ, receptive vocabulary and gender. Due to time constraints, FSIQ was measured using the two-subtest version (matrix reasoning and vocabulary) of the Wechsler Abbreviated Scale of Intelligence (WASI) (Psychological Corporation, 1999). To ens Scale (BPVS; Dunn, Dunn, Whetton, & Burley, 1997). Overall, there were no statistically significant differences between the ASD and TD groups on any of the matching criteria (see Table 1).

2.2. Measures

2.2.1. Planning: Tower of London (ToL; Culbertson & Zillmer, 2005)

Children were presented with a prearranged sequence of three different coloured beads on three different sized pegs. They were required to move the beads to match a goal state determined by the examiner and shown on a parallel board of pegs, in as few moves as possible and in accordance with prespecified rules. Standardised scores were recorded for the total number of moves and the total number of rule and time violations. The traditional ToL task was administered to help explore whether the preserved performance reported by Happé et al. (2006), on a computerised version of this task, reflected reduced task demands or intellectual functioning within the normal range.

2.2.2. Mental flexibility: Wisconsin Card Sorting Task (WCST; Heaton, 2003)

The WCST-64: Computerised Version 2 Research Edition (WCST-64™: CV2) required children to sort cards according to one of three unspecified rules (colour, number, shape) but in accordance with feedback about whether the choice was correct or incorrect. Standardised scores were recorded for total number of errors and perseverative errors. The computerised version was administered to reduce social task demands.

2.2.3. Response inhibition: Stroop (Stroop, 1935)

A single-trial computerised version of the Stroop was administered, using the colours; red, green, yellow and blue. Children had to make a key press response to indicate the colour of the ink that the word was written in. There was an inter-stimulus interval of

Table 1
Participant characteristics: means (standard deviations).

	ASD ($N = 54$) Means (SD)	TD ($N = 54$) Means (SD)	t	p
Age (months)	150.46 (33.55)	144.96 (28.03)	.92	.36
FSIQ	103.53 (10.54)	104.80 (9.07)	.67	.51
BPVS (ss)	99.70 (18.80)	100.94 (17.51)	.36	.72
Male:female	42:12	42:12		

1600 ms, during which a fixation cross was presented in the middle of the screen. There were eight practice trials, followed by 48 experimental trials with 50% congruence. Performance was scored for the difference in RT between congruent and incongruent trials, correct incongruent responses and correct incongruent RTs. The computerised single trial version was administered as, in addition to a potential reduction in social task demands, this task has been reported to be more sensitive to inhibition difficulties than standard card versions (Perlstein, Carter, Barch, & Baird, 1998).

2.2.4. Response inhibition: Junior Hayling Test (Shallice et al., 2002)

In Section A, children had to complete 10 simple sentences correctly, whilst in Section B they had to complete 10 simple sentences incorrectly. Children were instructed to complete sentences as quickly as possible. Responses were timed using a stopwatch, starting when the last word of the sentence was read and stopping when the child produced a response. In Section A, performance was scored for the number of correctly completed sentences. In Section B, three points were given for a correctly completed sentence, one point for a semantically related word and 0 points for an unrelated word. To investigate strategy formation, children were asked if they had used a particular trick to help them think of incorrect words (e.g. looking around the room).

2.2.5. Generativity and self-monitoring: Verbal Fluency

Children were required to generate as many different items as possible in accordance with the semantic Verbal Fluency category cues of *animals*, *fruit & vegetables* and *clothes.* Each cue was presented for 60 s. Correct responses and perseverations (repetition of a response) were recorded.

2.3. Procedure

Children were tested individually at home or school by one of two researchers. Testing took place within the context of a larger study examining autobiographical memory, where children were seen on three separate occasions for approximately 60 min each. All tasks were presented in a fixed order, with executive measures intermixed with autobiographical memory measures. The WASI, BPVS and Verbal Fluency tests were administered in the first session, the WCST and Stroop were administered in the second session and the ToL and Junior Hayling Test in the final session. Children were encouraged with positive comments throughout testing; however no direct feedback was given by researchers.

3. Results

To investigate group differences, a one-way analysis of variance was performed on each subtest. The assumption of homogeneity of variance was violated for some of the subtests (see Table 2). Significant performance differences did not however alter when non-parametric tests were conducted; therefore *F*-statistics are reported for all subtests. To investigate the effect of age on performance, Pearson's *r* was used to correlate performance scores with age for each subtest. This analysis was conducted separately for the TD and ASD groups. As a relatively large number of statistical tests were conducted a significance level of $p < .01$ was set in order to avoid Type I errors. However to avoid Type II errors items with *p* values of <.05 are also noted. Table 2 shows executive function test scores, *F*-statistics, Pearson's *r* and significance levels.

ToL: Children in the ASD group used significantly more moves to complete problems and made significantly more rule violations than controls. They also exhibited a tendency towards an increased number of time violations. The TD group exhibited a significant positive correlation between the number of rule violations made and age. There were no other significant age related effects.

WCST: Total number of errors and perseverative errors did not differ significantly between groups, though there was a tendency for children with ASD to make more perseverative errors than controls. In the TD group there was a significant correlation between age and the total number of errors produced; there was also a

Table 2
Executive Function test performance.

	ASD	TD	ANOVA		Correlation with age			
	Means (SD)	Means (SD)			ASD		TD	
			F	*p*	*r*	*p*	*r*	*p*
ToL								
Move score	88.74 (20.74)	99.04 (18.18)	**7.53**	**<.01**[*]	−.001	.47	.16	.24
Rule violations	81.76 (20.30)	98.93 (11.48)	**29.26**[†]	**<.001**[*]	.15	.28	**.36**	**<.01**[*]
Time violations	95.22 (19.02)	102.30 (12.16)	5.30[†]	.02	.14	.32	.06	.68
WCST								
Total errors	104.26 (16.95)	107.56 (17.71)	1.01	.31	.19	.16	**.38**	**<.01**[*]
Perseverative errors	108.11 (21.92)	116.24 (20.81)	3.91	.05	−.25	.07	.31	.02
Stroop								
Incongruent trials	22.04 (4.09)	23.61 (.83)	**7.67**[†]	**<.01**[*]	.28	.04	**.44**	**.001**[*]
Incongruent RT	1.21 (.38)	1.06 (.28)	5.53	.02	**−.40**	**<.01**[*]	−.28	.04
RT difference	.16 (.19)	.11 (.14)	2.38	.13	−.05	.71	−.02	.89
Junior Hayling Test								
A: total score	9.13 (1.10)	9.50 (.82)	3.94	.05	**−.39**	**<.01**[*]	.26	.06
A: time	1.02 (.80)	.80 (.54)	2.68[†]	.11	**−.35**	**<.01**[*]	−.24	.08
B: total score	5.41 (5.50)	3.41 (3.50)	5.07	.03	−.13	.36	−.13	.37
B: time	3.13 (2.00)	2.33 (1.51)	5.56	.02	−.15	.28	−.08	.58
B: completed	.63 (1.55)	.15 (.63)	4.50[†]	.04	−.15	.27	−.19	.17
B: semantic	3.41 (1.91)	2.94 (2.46)	1.19[†]	.28	.09	.54	-.03	.86
B: strategy (%)	50.00	70.37	4.68[‡]	.03				
Verbal Fluency								
Total	48.33 (16.29)	49.81 (10.68)	.32	.57	**.54**	**<0.001**[*]	**.51**	**<.001**[*]
Perseverations	1.31 (2.02)	.52 (.82)	**7.21**[†]	**<.01**[*]	.03	.86	−.27	.04

[‡] Chi-square statistics reported due to nominal data.
[†] Heterogeneous variances.
[*] $p < 0.01$.

tendency for perseverative responses to be related to age. There were no significant correlations with age in the ASD group.

Stroop: The difference in RT between congruent and incongruent trials did not differ significantly between groups. However, children in the ASD group correctly inhibited significantly fewer incongruent items than controls and they tended to be slower in doing so. In the TD group there was a significant positive correlation between age the number of correctly inhibited incongruent items; there was also a tendency towards a negative relationship between age and the speed at which incongruent items were inhibited. Similarly, the ASD children exhibited a tendency towards a positive relationship between age and the number of correctly inhibited incongruent items and a significant negative correlation between age and the speed at which incongruent items were inhibited.

Junior Hayling Test: Performance on this task did not differ significantly between groups. However, children with ASD exhibited a tendency towards poorer performance on Section B, with an increase in overall scores, response times and the number of incorrectly completed sentences. Fewer children with ASD also reported using a specific strategy to complete sentences than controls. For the ASD group there was a significant correlation between age and performance on Section A, There were no significant effects of age on Section B for the ASD group, nor were there any significant age related correlations on either Sections A or B for the TD group.

Verbal Fluency: The ASD and TD groups did not differ significantly for the total number of items correctly generated although, children with ASD generated significantly more perseverative responses than controls. In both groups there was a significant correlation between age and the number of items generated. The TD group also exhibited a tendency towards a negative relationship between age and the number of perseverative responses generated.

4. Discussion

The current study aimed to address previous methodological limitations to investigate the nature of executive functions in children with ASD compared to stringently matched TD peers. To exclude the possible impact of intellectual disability on executive dysfunction, only children with IQ's in the normal range were included.

On the WCST, performance did not differ significantly between ASD and TD groups; however, children with ASD tended to make more perseverative responses. This was consistent with their performance on the VF paradigm, where despite generating a normal number of items they produced significantly more perseverative responses than controls. Children with ASD were also significantly poorer than controls at inhibiting incongruent items on the Stroop and consistently poorer on the inhibition section of the Junior Hayling. Impaired performance was also reported on the ToL, with a significant increase in moves and rule violations for children with ASD compared to controls. Thus, compared to TD peers, children with ASD exhibited a specific pattern of performance across a range of executive measures. How do these research findings compare with or add to previous research in this area?

Preserved performance on the WCST is consistent with previous studies that have reported normal mental flexibility for children with ASD of average intelligence (Ozonoff, 1995; Rumsey, 1985) or who were matched to controls on the basis of verbal functioning (Liss et al., 2001). Nevertheless, children with ASD did tend to generate more perseverative errors than controls. This suggests that although children with ASD were able to shift sets as accurately as controls, their ability to self-monitor performance by utilising feedback to inhibit prepotent responding was poorer.

Consistent with this tendency, children with ASD also produced significantly more perseverative responses on the VF paradigm. This failure to inhibit previously generated responses may reflect reduced self-monitoring, which would be consistent with studies that have reported post-hoc difficulties in self-monitoring for individuals with ASD (Hughes, 1996; Russell & Jarrold, 1998, 1999). Nevertheless, children with ASD did not differ from controls for the number of lexical items produced. This finding is in agreement with previous studies that have reported preserved Verbal Fluency performance for individuals with ASD (Boucher, 1988; Scott & Baron-Cohen, 1996). Thus, despite reduced response inhibition or self-monitoring, generativity performance was preserved in children with ASD.

Although interference effects (RT difference) did not differ significantly between children with ASD and controls on the Stroop task, children with ASD were, significantly poorer at inhibiting incongruent items, with regards to both performance accuracy and speed of response. Typical interference effects are consistent with previous studies reported in the literature (Hill & Bird, 2006; Ozonoff & Jensen, 1999; Ozonoff & Strayer, 1997; Ozonoff et al., 1994; Russell et al., 1999; Schmitz et al., 2005). The impaired inhibition of incongruent items is, however, a novel finding, though it is noted that the number of correctly inhibited incongruent items is not normally reported. This research finding may reflect task presentation, with the computerised single trial version of the Stroop being more sensitive to inhibition difficulties than standard card versions (Perlstein et al., 1998). Nevertheless, difficulty inhibiting incongruent items is consistent with the impaired inhibition of prepotent responses that is reliably reported on the Windows Task for individuals with ASD (Bíro & Russell, 2001; Hughes & Russell, 1993; Russell et al., 1991, 2003). Thus, in the current study, although children with ASD exhibited the same level of interference from competing information as controls, they were poorer at successfully inhibiting prepotent responding.

Consistent with this, children with ASD exhibited a reliable tendency towards poorer performance on the inhibition section (Section B) of the Junior Hayling, with longer response times and an increase in the number of incorrectly completed sentences. Fewer children with ASD also reported using a strategy (e.g. selecting objects in the room) to help them think of unrelated words. Thus, reduced performance on this task for children with ASD may reflect difficulties inhibiting prepotent responses and/or strategy formation. This suggestion contrasts with that of Hill and Bird (2006) who proposed a generativity account of impaired performance on this task. With respect to our data, this account cannot be sustained since generativity performance was preserved. This disparity may be explained by the differences in sample (i.e. children vs. adults). Strategy formation was also not directly assessed in the Hill and Bird study. In summary, our data suggest that it is reduced inhibition of prepotent responses or strategy formation that drives poor performance across this and other executive measures for children with ASD.

Finally, impaired performance was reported for children with ASD on the ToL, with a significant increase in both the number of moves made to complete problems and the number of rule violations made. There was also a tendency towards an increase in the number of time violations made. The results indicate clear impairments in planning skills and extend previous research studies that have only reported such planning difficulties on traditional tower tasks for individuals with ASD whose IQ's fall at the lower end of the normal range (Geurts et al., 2004; Hughes et al., 1994; Ozonoff & Jensen, 1999; Ozonoff & McEvoy, 1994; Ozonoff et al., 1991). Reduced strategy formation, as discussed above, would also be consistent with the notion of a planning deficit, as a strategy is a plan designed to achieve a particular goal.

However, Happé et al. (2006) documented preserved planning on the computerised version of the ToL for children with ASD of normal intelligence. One possible explanation for the disparity between these studies is that task presentation and the degree of social interaction may influence performance. For example, the human administration of tasks may enhance cognitive impairments that might otherwise be borderline and/or the computerised administration of tasks may attenuate cognitive impairments that might otherwise be present. On this basis one would, however, predict superior performance on all computerised tasks, which as discussed above was not the case for the Stroop. Alternatively, the disparity between research findings reported for the standard and computerised version of the ToL may reflect differences in the way in which participants are instructed to complete the task. On the computerised version participants are told the minimum number of moves required to make the goal pattern and they are encouraged not to make the first move until they are confident they can execute the full solution in the required number of moves. This information is not presented on the standard version, where participants are instructed to make the goal pattern in as few moves as possible. The additional information presented for the computerised version may aid planning performance for children with ASD by reducing prepotent responding and/or constraining the number of moves made to make the goal pattern. Thus, as well as identifying the cognitive components that are required to successfully complete these tasks, there is a need to establish the effects that task presentation and task instructions may have on cognitive performance for children with ASD.

To investigate whether children with ASD exhibited typical age-related gains in executive functioning, performance was correlated with age on each subtest for both the ASD and TD groups. On the WCST, TD children exhibited a significant relationship between performance and age, indicating a reduction in errors and a tendency towards fewer perseverative responses with age. TD children also exhibited a significant relationship between age and the number of rule violations made on the ToL, indicating an increase in adherence to rules with age. Performance did not correlate significantly with age for the number of moves made or time violations. On the Stroop, both the TD and ASD groups exhibited significant relationships between inhibition performance and age, with a more prominent increase in the number of correctly inhibited items with age for the TD group and a more prominent increase in the speed at which these items were inhibited with age for the ASD group. Both groups also exhibited a significant relationship between Verbal Fluency performance and age. TD children also exhibited a tendency towards the generation of fewer perseverative responses with age. Although there were no significant age related effects for accurately inhibiting items on the Junior Hayling, children with ASD exhibited a significant relationship between performance on Section A and age, indicating increased accuracy and speed for correctly completing sentences.

These findings indicate age-related gains in mental flexibility, planning, speed of response and lexical development. In relation to TD controls, children with ASD did not exhibit typical relationships between age and performance on the WCST, rule violations on the ToL or Verbal Fluency perseverations. The common cognitive components that contribute to performance on each of these measures are self-monitoring and response inhibition. This therefore suggests that children with ASD may fail to exhibit typical age-related gains in response inhibition and/or self-monitoring, the latter of which may contribute to the former. This would be consistent with the above discussions. It would also be consistent with the patterns of age-related gains in performance reported on the Stroop, as whilst the TD group exhibited a highly significant relationship between the number of correctly inhibited items and age ($p < .001$), the ASD group did not ($p = .04$). Thus, compared to TD controls, age-related gains in prepotent responding were less evident for children with ASD.

The failure to find age-related gains in performance for children with ASD, on tasks for which their performance was selectively impaired, suggests that the nature of the executive impairment reported for children with ASD remains relatively stable across the childhood years. The findings in children with ASD as well as TD controls also highlights the fact that distinct cognitive components, with potentially independent developmental trajectories, may underpin successful performance on different aspects of these tasks. These research findings are consistent with studies reported in the developmental literature (Baker, Segalowitz, & Ferlisi, 2001; Broki & Bohlin, 2004; Huizinga, Dolan, & van der Molen, 2006; Welsh, Pennington, & Grossier, 1991; Williams, Ponese, Schachar, Logan, & Tannock, 1999).

5. Concluding comments

The current research aimed to address previous methodological limitations in studies of executive functions in children with ASD. When matched with TD controls for IQ and language levels participants with ASD exhibited a specific pattern of executive impairments, with poor performance on measures tapping planning, the inhibition of prepotent responses and self-monitoring. In contrast, mental flexibility and generativity was preserved. Atypical age-related performance differences were also reported on measures tapping response inhibition and self-monitoring.

Thus, the current research findings support a multidimensional notion of executive functions, with difficulties in planning, inhibition and self-monitoring across the childhood years appearing to reflect autistic symptomology and not intellectual disability or verbal difficulties. It is, however, noted that in children with ASD plus intellectual disability additional executive difficulties may be reported. The study highlights the need for further investigations to tease apart the impact that reduced self-monitoring may have on inhibitory performance, and in particular the inhibition of prepotent responses. The study also raises questions regarding the comparability of performance across different task presentation methods. In particular, there is a need for more studies exploring performance for the same group of children on both human and computerised versions of executive function tasks so that the component skills that underpin successful performance on each may be identified.

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