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ORIGINAL PAPER

Size Sequencing as a Window on Executive Control in Children with Autism and Asperger's Syndrome

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Abstract A study is reported in which size sequencing on a touch screen is used as a measure of executive control in 20 high-functioning children with Autistic Spectrum Disorders (ASD). The data show a significant and age-independent effect of the length of sequence that can be executed without errors by these children, in comparison with a chronologically age-matched group of children with normal development. Error data and reaction times are analysed and are interpreted as revealing a constraint on the prospective component of working memory in children on the autistic spectrum even when there is no change in goal or perceptual set. It is concluded that the size sequencing paradigm is an effective measure of executive difficulties associated with autism.

Keywords Executive functioning · Autism · Asperger's syndrome · Working memory · Sequencing

Introduction

It has long been noted that individuals with autism display a general problem of response inflexibility, similar to that exhibited by patients with frontal lobe lesions (Ameli, Courchesne, Lincoln, Kaufman, & Grillon, 1988). There is a growing consensus that these deficits in executive control result from difficulties in voluntary attention switching when completing a task (Courchesne et al., 1994; Goldstein, Johnson, & Minshew, 2001; Pascualvaca, Fantie, Papageorgiou, & Mirsky, 1998). Consensus notwithstanding, however, the precise nature of these difficulties remains elusive (Hill, 2004).

The widespread use of the Wisconsin Card Sort Task (WCST) (see Ozonoff, 1997 for a review), and the Intradimensional/Extradimensional shift (IDED) paradigm (Hughes, Russell, & Robbins, 1994; Ozonoff & Jensen, 1999; Turner, 1997) has highlighted the cognitive set-switching element in participants with autism. Both these tasks show that people with autism experience difficulties when having to change from their previous solution or basis for response selection, implying that the core problem arises from establishing new response categories rather than in executing the primary task. This has led others to emphasise 'frontal' type difficulties in inhibiting prepotent but incorrect responses as revealed by forward planning tasks such as the Tower of London/Hanoi and Stockings of Cambridge tasks (Hughes et al., 1994; Ozonoff & Jensen, 1999; Ozonoff, Pennington, & Rogers, 1991; Robbins, 1997), sequencing and SOPT tasks (Turner, 1997). In recent years, researchers have begun to note, furthermore, that deficits in planning and inhibition are not all-or-none, but subject to the degree of cognitive load on the participant whilst performing the task (Roberts, Hager, & Heron, 1994; Russell, Jarrold, & Henry, 1996)—a finding leading Roberts and Pennington (1996) to suggest that there should be an 'interactive' model for autism as there is for frontal lobe disorders; i.e. one that takes account of degree of prepotency of competing responses in relation to the working memory demands of the task. Certainly, the

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on-line memory demands of the Towers tasks can be complex, often requiring many possible prospective moves to be held in memory at the same time. Where this has been (unusually) systematically measured, it was found that group differences between individuals with autism and control participants emerged on the Tower of Hanoi only where the possible moves were as many as 4 or 5 in number (Robbins, 1997).

The difficulties revealed by the Tower of Hanoi/London tasks in participants with autism are in terms of the relatively higher number of redundant moves, suggesting selective difficulty in inhibiting an inappropriate move 'in the mind's eye'. Simple perceptual tasks on the other hand have indicated attentional disengagement problems at the more explicit level of voluntary oculomotor control (Minshew, Luna, & Sweeney, 1999; van Der Geest, Kemner, Camfermann, Verbaten, & Van Engeland, 2001). For example, the anti-saccade task, developed by Hallet (1978) in which participants must follow an instruction to look away from a previous fixation point, has been found by Minshew and colleagues to detect selective difficulties in individuals with autism reflecting 'an impaired capacity of the prefrontal cortex for volitionally suppressing context-inappropriate reflexive responses' (Minshew, Johnson, & Luna, 2000, p. 134). This task has also been subject to explicit and systematic variations of cognitive load; the working memory demands were increased by Roberts et al. (1994) by introducing a secondary irrelevant task (simple addition) and this manipulation did induce errors in normal adults similar to those described in patients with frontal lesions. It remains for such load manipulations to be carried out with participants with autism, however.

In summary, the 'goal-directed' tasks that reveal executive difficulties in autism imply a root problem at the level of visuo-motor control but one that remains to be clarified in terms of its interaction with working memory load.

Memory tasks on the other hand are not usually designed with an executive goal in mind such as sorting or planning and, thus, for their part make little or no demand on perceptual disengagement from a competing alternative. A box search task used by Ozonoff and Strayer, for example (Ozonoff & Strayer, 2001), required adult participants to remember which of six coloured boxes (with a target box hiding 'treasure') had been searched on a computerised display, but the boxes were moved around after every search to prevent correct responses arising from remembering locations, thus also removing the prepotency of a previously searched location. Similarly, the 'boxes' task used by Griffith, Pennington, Wehner, and Rogers (1999) require child participants to remember a target object indicating the location of a reward (with or without preservation of additional location information), but as the task is solved once the object has been found, there is no requirement to visually disengage from a previously rewarded stimulus. Negative results from tasks such as these have contributed to the view that the executive difficulties manifest by individuals with autism are not sourced to working memory per se (Ozonoff & Strayer, 2001). A recent exception is the Spatial Working Memory task used by Goldberg et al. (2005) in which high-functioning children with autism had to search boxes for tokens in order to fill a container on one side of a computer screen; a return to an empty (or emptied) location would was scored as a search error. Here children did have to self-monitor their previous searches in relation to remaining plausible locations and the number of locations proved to be an important factor, showing significant difficulties for children with autism on mid-difficulty (6-box) and maximum difficulty (8-box) problems.

This last study encourages the view that gradable, on-line, visuo-spatial tasks provide a good basis for developing the interactive approach to executive failures in autism. So far, however, the interactive approach has had little recourse to a paradigm that clearly tests its central premise: that systematic variations on cognitive load within an on-line task can 'measure' executive deficits. A developmental test that has exactly this potential is size seriation. Highly explicit in its executive demands, the classic version first employed by Piaget and Szeminska (1952), requires children to assemble (usually 8–10) objects in a line according to an ascending or descending sequence. 'Operational' or expert seriation requires accurate non-trial-and-error selection and placement of every rod; an accurate sequential production without error. Applicable to a wide age range, seriation is non-verbal, can be subject to systematic loading (by varying the number of objects to be searched), and thus uniquely combines the elements of visuo-spatial information processing, working memory and visual attention switching from alternative competing objects. If the interactive hypothesis is correct, then children with autism would surely be expected to fail on this task at some point relative to typically developing children and in ways that would be amenable to individual assessment as a function of the task loading (number of items in the set to be interrogated).

Certainly the first report of size seriation in the autism literature (Hermelin & O'Connor, 1970; O'Connor & Hermelin, 1965) did find a dramatic group difference between (both speaking and non-speaking) low-functioning children with autism and mental age matched controls on a simple five item test—and a significant difference on eight item single and multiple seriation has been reported subsequently by Yirmiya and Shulman (1996) for children with a mental age of around 6 years. Yet Yirmiya and colleagues failed to obtain a significant effect with these tasks when the participants were high-functioning children

with a chronological age of 9 years and above. One possible reason for this is that the classic form of the task itself is not a well-calibrated test of executive functioning, especially for older, more expert seriators (see Chalmers & McGonigle, 1997; McGonigle & Chalmers, 1996 for an extensive discussion).

A computer-based version of size seriation has been developed in our lab for use with monkeys and normally developing children to afford a more precise evaluation of sequential control (Chalmers & McGonigle, 1997; McGonigle & Chalmers, 1993, 1996; McGonigle & Chalmers, 2007, in press; McGonigle, Chalmers, & Dickinson, 2003). The advantage over the classic task is that there is no (confounding) visible consequence of each selection; the items (shapes such as stars varying in size) remain in place and the test pool size and layout remains the same until all items have been selected. Only completely correct exhaustive searches in a monotonic (ascending or descending) sequence are regarded as correct. For added depth of measurement, the paradigm is learning-based participants are not assessed on a one-off basis (as initial failure is subject to many interpretations) but in terms of how quickly or otherwise they learn to execute error-free productions at increasing levels of difficulty, and in terms of the type of error committed during learning.

In our developmental studies, there was a clear age difference between 5 and 7-year-old children in their ability to execute accurate productions as set size increased from five to seven items (McGonigle & Chalmers, 1993, 1996, 2007, in press). Informed by these findings, in the study reported below (involving children aged from 7 years onwards), the 'entry level' was set at nine items, increasing to a maximum of 12. The central demand on executive control within this task is to search for the next biggest or next smallest in the sequence, inhibiting responses to—and disengaging attention from—likely candidates of similar size, until the full stimulus array has been interrogated. A secondary and separate demand on attention switching was introduced by way of comparison, as all participants had to reverse the order of searching as randomly cued by the colour of the items.

Methods

Design

An inter-group design was used, comparing children with Autistic Spectrum Disorders (ASD) against a typically developing control sample (matched for chronological age) at increasing levels of task difficulty. An entry level of nine items was used for all participants, but allowance was made for children who might fail to reach learning criterion on this level by having a 'crashback' feature in the experimental design, allowing such children to attempt the task at lower levels (from seven items). This is illustrated in Fig. 1.

Participants

The participants were 20 school-aged children (18 boys and 2 girls) at the higher functioning end of the autistic spectrum and 20 control participants (12 males and 8 females) matched for chronological age. All children were white English-speaking and drawn from highly similar socio-economic backgrounds, with parents of professional or semi-professional status. The mean age for children in the autistic spectrum group (hereafter described as the ASD group) was 10 years 0 months (10.0) (range 6.8–13.8; SD 2.3), and for the control children, the mean age was 9 years 5 months (9.5) (range 7.0–13.9; SD 2.2). The criterion for inclusion in the group of children with ASD was a confirmed diagnosis by at least one senior paediatric consultant of Autism or Asperger's syndrome. Further confirmation of all diagnoses were carried out by the first author using the Autism Diagnostic Schedule (ADI-R) (Lord, Rutter, & Le Couteur, 1994), from which it was found that all children with a clinical diagnosis of Kanner or infantile autism scored above the cut-off on all four criteria of the diagnostic algorithm; those diagnosed with Asperger's syndrome scored above the cut-off on at least two of the criteria. The mean scores (range and SD) for the autism subset were: 22.6 (12–26, 4.4) for Qualitative Abnormalities in Reciprocal Social Interaction; 18.7 (14–23, 3.5) for Qualitative Abnormalities in Communication (QAC); 8.7 (4–20, 4.6) for Restricted, Repetitive and Stereotyped Patterns of Behaviour and 3.3 (2–4, 0.6) for evidence of abnormality in the first 3 years. The corresponding scores

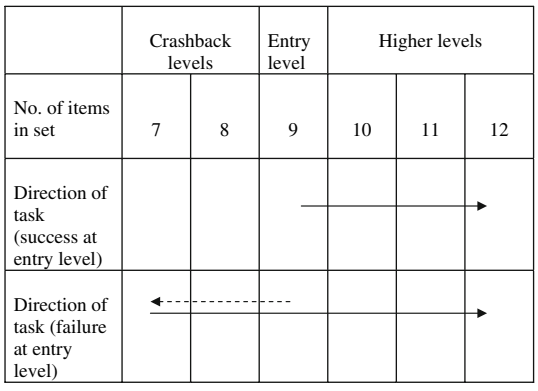

Fig. 1 The task design

for the children with Asperger's syndrome were 14.8 (9–23, 5.0); 12.6 (5–20, 4.9); 4.7 (2–8, 2.0) and 1.6 (0–4, 1.4), respectively.

Attendance at mainstream school and/or average to above average IQ recorded on the clinical record was the first selection criterion used to indicate that the sample fell within the 'higher functioning' end of the spectrum. Confirmation that all participants had normal to high levels of non-verbal intelligence was obtained using the Kaufman ABC-R mental processing scale (Kaufman & Kaufman, 1983) and the WISC-III performance scale (Wechsler, 1992) for children over the age of 12 years 6 months. The same IQ tests were used with the control group. All children in both groups were within the normal to above average range, i.e. with a percentile rank of between 50 and 100. The mean percentile rank[1] derived from these tests was 76 (range 50–91 and SD 19.9) for the ASD group, and 90 (range 70–99 and SD 8.6) for the control group.

Stimuli and Task

The software used to implement the task design forms part of a package called Computer Assisted Seriation Training (CAST) written by Lorenzo Vigentini, Edinburgh University. Presented as a game on a computer drive touch screen, the game elements consisted of a random array of coloured shapes (stars) that had to be touched in either ascending or descending order of size as cued by the colour of the stars (blue or pink) (see Fig. 2). The stimuli ranged from 5 to 38 cm in size with a 3 cm interval difference in diameter. In order to increase the number of stimuli whilst preparing children for the level of discriminability that would be required by the highest level (12), lower levels consisted of consistent subsets of this stimulus set (e.g. level 9 was composed of items 1,2, 4, 5, 7, 8, 10, 11, 12).

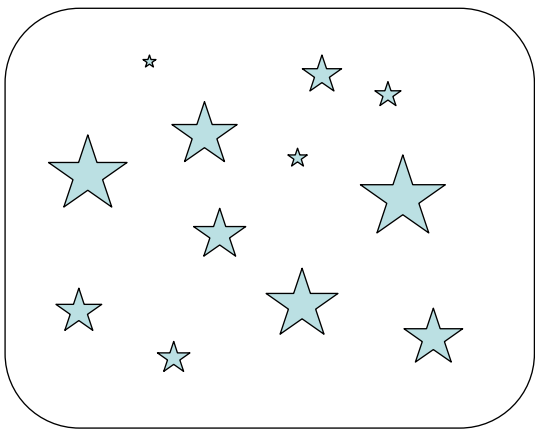

Fig. 2 An example of the size sequencing task at level 12. The colour of the stars (*blue* or *pink*) indicates whether they should be touched in ascending or descending order

[1] Percentile ranks are used to allow comparability across the WISC-R and the K-ABC

Designed to be as entertaining as possible, the computer-interactive features of the game were auditory and graphic corrective feedback on an immediate (touch by touch) and deferred (trial-by-trial) basis. For immediate feedback, the stimuli would become briefly animated into a smiling face accompanied by a high-pitched tone if touched in the correct sequence, but into a sad face accompanied by a lower tone if touched out of sequence. Trials terminated only when every item had been touched at least once and were followed by deferred feedback. Here, a completely correct trial (no wrong touches) was followed by a brief animated clip of a cartoon character 'whooping' with joy, whilst an incorrect trial (one or more incorrect touches) was followed by a clip of the character with head in hands posture, exclaiming 'doh…'. Background features of the game included soft background music, a box at the side of the screen depicting the current level, and animations to indicate that the child was proceeding to a new level. The game was preceded by a demo task (involving four trials with five items) where the children were told that they could they could win by 'touching all the stars in the right order without making a mistake'.

Learning criteria were set at four completely correct trials out of six. If criterion was met, then the participant proceeded to the next level. Three opportunities were given on every level to meet criterion, thus setting the minimum number of learning trials per level at 6; the maximum at 18. If participants failed to meet criterion on the entry level (9), they were taken back to the crashback level 7, Training then resumed as for the higher levels, proceeding past level 9 if subjects now met criterion on this level. Children exited the game only after attempting all 18 trials at the failed level.

Results

Level Reached

Number of Children Proceeding to 'Crashback' Levels

Two children (both with Asperger's syndrome; one 7 years and 2 months, the other 8 years and 6 months) failed to reach criterion at any level. Table 1 depicts the number of remaining children in both groups who either succeeded in reaching criterion on at least one level of the task. The table is subdivided into those who were able to succeed at the first attempt on level 9 and those who required crashback training from level 7. As this table indicates, the majority

Table 1 Number of children reaching final criterion as a function of level

	Crashback levels		Entry level	Higher levels		
No. of items in set	*7*	*8*	*9* → *9*	*10*	*11*	*12*
Children with ASD (n =18)	7	5	2 → 0	1	1	2
Children with normal development (n = 20)	3	0	5 → 3	0	3	6

	Total failing or requiring crashback	Total succeeding without crashback
ASD (n = 20)	14	6
Nml dvpt (n =20)	6	14

of normally developing children did not require the crashback levels whilst for the children with ASD, the reverse was the case. A chi-squared test shows that the distribution of children in the categories crashback/no crashback is significantly different ($\chi^2(1) = 6.4$ and $p < 0.05$).

Mean Level Reached

Figure 3 depicts the final level that each child successfully achieved. A one-way analysis of variance and covariance (BMDP, 1992) shows that there is a significant difference between the two groups, with the children with autism reaching lower levels than the control children ($F(1) = 15.45$ and $p < 0.01$). The adjusted group means were 8.15 and 10.03, respectively.

There was significant covariance with age ($T = 3.59$ and $p < 0.01$). Figure 4 depicts this difference in terms of the

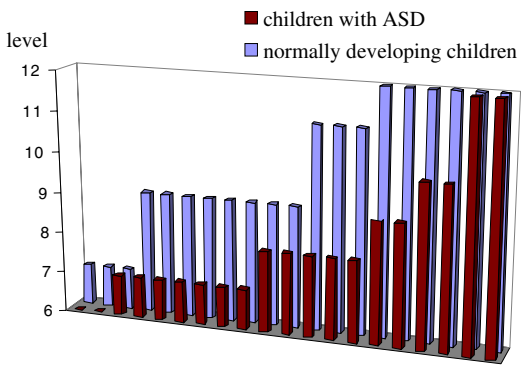

Fig. 3 Individual measures of success, showing final level reached, ranked from lowest to highest for both groups

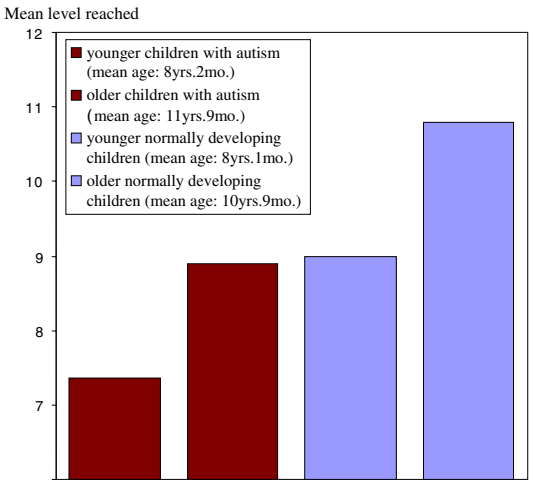

Fig. 4 A comparison of older and younger children in both groups in terms of mean level reached

older 10 and younger 10 children in each group. As this figure shows, the difference in mean level achieved is sufficiently large that the older children with ASD are performing at around the same level as the younger control children. No significant difference was found within the ASD group between the children with autism and the children with Asperger's syndrome on a one-way analysis of variance and covariance with age as the covariate ($F(1) = 0.13$; $p > 0.05$). The adjusted means were 8.16 for the autism sub-group and 7.88 for the AS sub-group.

The total duration of exposure to the task was not significantly different for the two groups [one-tailed $t(df = 37) = 1.42$ and $p > 0.05$]; the children with ASD were on the task for a mean of 43 trials (range 18–73); the control children for a mean of 36.5 (range 18–70).

Level Reached in Relation to IQ

To clarify the relationship between performance and IQ, a one-way analysis of variance and covariance (BMDP, 1992) was carried out using the standard scores from the mental processing sub-scale of the K-ABC as a co-variate.[2] There was significant covariance with IQ ($T = 3.2$ and $p < 0.01$), but there was still a main effect of group on level reached ($F(1) = 4.4$ and $p < 0.05$). To help clarify this further still, the lower bound outliers for IQ (i.e. with a percentile rank of below 75), were removed, along with their age-matched control participant, producing a subset of 12 children in each group, matched for age. In order to match them as far as possible on a measure of non-verbal

[2] Although 5 of the 40 children were above the age limit for this test, none had raw scores at ceiling and so it was deemed meaningful to use their scores as scaled for the oldest group.

IQ least likely to be confounded with sequential difficulties, the simultaneous sub-scale of the K-ABC was used.

No significant differences obtained for age and the standard scores for simultaneous processing (F distributions were non-significant at $p > 0.5$), whilst a significant effect of level reached remained ($t(22) = 2.69$ and $p = 0.01$). The effect remained significant when the five children over the age of 12 years 6 months were removed ($t(16) = 3.03$ and $p < 0.01$). This finding is summarised for the full subset in Fig. 5.

As IQ did not 'explain away' the sequential data, all subsequent analyses were conducted for the full set of participants.

Error Profiles

Number of Errors During Learning

As the difference in success between the groups was substantial, the only point of overlap at which errors during learning could be meaningfully compared across groups was level 9—the level at which all children entered the task. The mean number of error trials was 11.2 and 5.4 for the ASD and the control groups (representing a mean of 35 and 51% correct, respectively). A Student's t-test shows the mean numbers of error trials to be significantly greater for the ASD group [one-tailed $t(df = 38) = 3.26$ and $p < 0.01$]. The point during the sequence at which an error was most likely to be committed was between items 4 and 5 for both groups. No significant difference was recorded between the

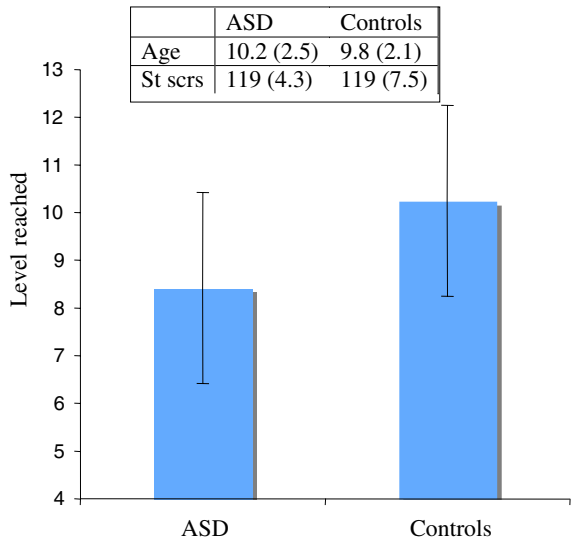

Fig. 5 Mean level reached for a matched subset of 12 ASD participants and 12 control participants. The accompanying table shows their mean age and standard scores (*St scrs*), on the simultaneous processing sub-scale of the K-ABC (standard deviations in parenthesis)

Autism and Asperger's sub-groups on a one-way analysis of variance and covariance with age as the covariate ($F(1) = 0.05$ and $p > 0.05$). (The 11 children with Autism recorded a mean performance correct at this level of 36% correct, whilst the nine children with Asperger's syndrome recorded a mean of 34% correct.)

Of the total first errors committed by both groups, few were made on the first stimulus; most (over 70%) were internal to the sequence, and, of these, the majority (over 95%) were of the 'forwards type', i.e. by skipping one or more intermediaries (rather than repeating a touch or returning to an item previously selected). The means for internal errors were 19.60 (forwards), 0.85 (repeat) for the ASD group and 16.55 (forwards) and 0.6 (repeat) for the controls. The start errors by contrast were more likely to reflect the selection of the wrong end-point, i.e. the wrong directional 'rule'. The means were 3.6 (wrong end-point), 2.8 (forwards) for the ASD group and 1.8 (wrong end-point) and 1.05 (forwards) for the controls. The distribution of error frequencies, however, was not significantly different for either group ($\chi^2(1) = 0.019$ and $p > 0.05$ for start errors and $\chi^2(2) = 4.88$ and $p > 0.05$ for internal errors).

Random Productions

First errors notwithstanding, there was a discernible difference in the way in which at least some of the children with ASD occasionally responded to the task as compared to the control children. That is, 11 of the 20 children in the ASD group sometimes produced seemingly random sequences with fewer than four items in consecutive order and in which first errors could not easily be classified as described above (and were discounted from that analysis). A mean of 3.5 such sequences (ranging from 1 to 12) were produced by these 11 children. None were made by the children in the control group.

Reaction Times

Figure 6 compares inter-touch intervals collapsed across all correct sequences performed at level 9 for all individuals in both groups, from which it can be seen that the children with ASD are consistently slower when executing the correct sequences than the control children. A one-way analysis of variance (BMDP P1V) shows the interaction between group and RT to be significant ($F(8, 224) = 59.07$ and $p < 0.01$).

Relationship with Autism Diagnostic Profiles

Whilst no differences emerged for the two sub-groups on the autistic spectrum, a final analysis was carried out as a

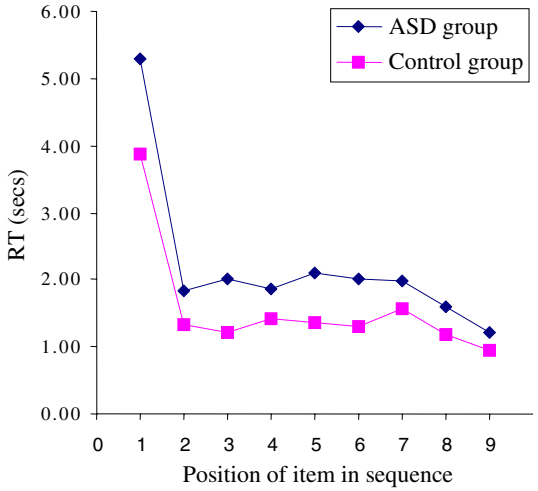

Fig. 6 Mean RT functions for correct sequences at level 9

check for any correlations between scores on the three sections of the diagnostic interview for the ASD group as a whole. These are: qualitative abnormalities in reciprocal social interaction (QRSI), QAC and restricted, repetitive and stereotyped patterns of behaviour (RRSB). The rank order correlation coefficient was not significant for the first of these (QRSI) ($R = 0.14$): but was significant for the other two ($R = 0.52$, $p = 0.01$, $R = 0.56$, $p = 0.01$, respectively), in each case showing an inverse correlation between the diagnostic algorithm score and the level attained by the child on the size sequencing test. IQ, by contrast, was not correlated with any of the diagnostic scores. The rank order correlations between the standard scores on the Mental Processing Sub-scale of the K-ABC and the diagnostic triad were $R = 0.15$, 0.13 and 0.09 for QRSI, QAC and RRSB, respectively.

Discussion

The results of this study have shown clear and significant differences between children at the high-functioning end of the autistic spectrum and typically developing children in their ability to sequence a set of items by size. A measure of these differences has been provided in terms of the number of items than can be accurately sequenced. The data from the ASD group showed sensitivity to the same within-sequence sources of difficulty as the control data. For both groups, success was subject to a developmental trend, but with an overall discrepancy between the control and the ASD group of almost 4 years. Older children with ASD (ranging between 9 years 8 months and 13 years 8 months) exhibited the same mean level of performance as typically developing children aged between 7 and 9 years 3 months, suggesting a possible attenuation of cognitive development in ASD.

Although a small percentage of the total productions (fewer than 5%) made by children on the autistic spectrum were too random to analyse, most were clear and valid attempts to seriate but with evident restrictions on the length of sequence that could be controlled without error. This is despite the fact that both groups spent equivalent amounts of time on the task overall. No differences were found within the ASD group between children diagnosed with Autism and those diagnosed with Asperger's syndrome consistent with Frith's speculation, 'it is doubtful whether impairments in executive functions will be found to be milder in Asperger syndrome than autism' (Frith, 2004, p. 680).

Although ASD group had a lower overall mean performance IQ, the results cannot be simply attributed to any between group differences on IQ. First, the effect of sequential difficulty remained even where IQ was used as a covariate—a procedure used by Goldberg et al. (2005) to control for IQ discrepancies between experimental and control groups. In addition, the present study included an attempt to at least 'match' a subset of the children, using a measure of IQ deemed least likely to be itself confounded with sequential and executive skills (the simultaneous processing sub-scale of the K-ABC) and these matched sub-groups still revealed a gross difference in terms of level reached on the sequencing task.

However, it is extremely unlikely that difficulties in executive skills as uncovered here would not influence more global IQ measures, given that most batteries involve an ad hoc mixture of different task demands, many of which are sequential in nature. Consequently, typically developing and ASD participant samples, selected for 'normal' IQ and matched for age, schooling and other variables are always likely to be different in terms of mean standard scores on IQ tests (see, e.g. Goldberg et al., 2005). Consequently, if the causes of mild intellectual impairments in high-functioning individuals with ASD are to be revealed using precise instruments and related to autistic symptomatology, then it is important that sample selection is not constrained a priori by over-rigorous matching on some or other global IQ measure. For these reasons the remaining analyses in the report were aimed at the ASD group as a totality (irrespective of IQ) in an attempt to pinpoint the nature of the executive problems that differentiated them from the control sample.

The first clue to this came from the loading factor in the task, which clearly reveals a restriction on the upper limits of sequencing skills in children with ASD, similar to that recently reported for spatial working memory by Goldberg et al. (2005). In the current study, neither visual disengagement nor motor inhibition per se can explain the selective sensitivity in children with ASD to the number of items in the set. This

finding points to a specific restriction on the number of competing items that can be searched (and disengaged from) to resolve any local discrimination when proceeding through the sequence. Accuracy of item selection therefore seems to be compromised in terms of the prospective component of working memory (most likely to be registered at the mid-point of the sequence). This component is the active interrogation of likely candidate stimuli to which a response may still have to be made, whilst holding in memory the item last touched. The heavy bias in the error data of all participants towards 'forwards' rather than 'backwards' errors, and the relatively small effect of rule switching, confirms that this is the main source of all incorrect seriation in this study. The extra attentional demands caused by increasing the immediate prospective search space has a greater impact on children with ASD.

This finding draws attention to an important distinction within the working memory demands of a serial executive task—the retrospective element—which retains previous responses in a temporary store, and the prospective component involved in keeping attention open to all sources of information relevant to the next response. For example, the treasures task used by Ozonoff and Strayer in which participants try to locate a 'treasure containing' box by remembering the colour of previously searched boxes, requires holding (all) the retrospective contents of the box searches in a temporary store—a feature that did not significantly distinguish individuals with autism from control participants for (Ozonoff & Strayer, 2001). As the authors point out, this contrasts, with the working memory demands of the Tower of Hanoi/London tasks (and, we submit, the current task) which 'necessitate generating and holding potential moves in an ''on-line'' state while considering the consequences of each and choosing among the alternatives' (Ozonoff & Strayer, 2001, p. 257).

Deficits in the voluntary active look-ahead part of the working memory could arise of course from general response impulsivity. This would result in the motor response being engaged before adequate interrogation had taken place—a tendency that would become statistically more likely to affect performance, the longer the task. If this was the reason behind poor executive control in the current study, therefore, it would be expected that the children with ASD would be characterised as having faster inter-touch intervals. This was not the case. Instead the children with ASD were actually slower than the control children when seriating, a finding consistent with a study on classic seriation by Yirmiya and Shulman (1996). Response impulsivity has also been disconfirmed in other contexts as an explanation of the executive dysfunction in autism (Ozonoff, 1997).

If not impulsivity, but rather the converse—a slowness in engaging the next response—then the remaining explanation would seem to come down to a fundamental wetware restriction on processing capacity (Courchesne et al., 2001; Dawson, 1996). Informal feedback from parents of children in the ASD group identified expressions of this problem in everyday life. Some were similar to the lab-based sequencing task, such as an inability to visually search in complex and unfamiliar surroundings such as supermarket shelves; others indicated an analogous problem in auditory working memory, such as 'losing track' when reciting multiplication tables or writing out long numbers in thousands, hundreds, tens and units. In almost all cases parents described their children as suffering anger and frustration when a complex serial or search problem seemed to suddenly become 'painfully' hard.

In summary, the use of size sequencing as a measure of executive control in children with ASD has both identified and measured a within-task working memory problem in a visuo-spatial domain. Specifically it indicates a restriction on the capacity for holding open attentional channels long enough to prospectively process all information immediately relevant to the next response. We see these results as consistent with Pennington's conclusion that 'modular' explanations of autism may be sourced to some 'very general and basic aspect of the human cognitive system' (Pennington et al., 1997, p. 171) that will in turn help to clarify the relationship between ASD and the high levels of intellectual impairment associated with the spectrum as a whole. The correlations that obtained at least in this small sample, between seriation and at least two important indices of autism (communicative abnormalities and restricted, repetitive and stereotyped behaviours) encourages the view that executive failures have a deep if yet to be explained relationship with the symptomatology of autism. If this is indeed the case, then clear measurement of this aspect cognitive functioning is paramount. The size sequencing task described here offers such a basis for calibrated measurement. Its non-verbal nature and inherent gradability also make it suitable for use with lower functioning, minimally verbal or non-verbal children. Such experiments are ongoing in our lab.

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