Multiple cognitive capabilities/deficits in children with an autism spectrum disorder: ‘Weak’ central coherence and its relationship to theory of mind and executive control

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This study examined the validity of ‘weak’ central coherence (CC) in the context of multiple cognitive capabilities/deficits in autism. Children with an autism spectrum disorder (ASD) and matched typically developing children were administered tasks tapping visuospatial coherence, false belief understanding and aspects of executive control. Significant group differences were found in all three cognitive domains. Evidence of local processing on coherence tasks was widespread in the ASD group, while difficulties in attributing false beliefs, and components of executive functioning were present in fewer of the children with ASD. Furthermore, weak CC was unrelated to false belief understanding, but aspects of coherence (related to integration) were associated with planning ability. Few associations were found between cognitive variables and indices of autistic symptomatology. Implications for a multiple capabilities/deficits view of autism are discussed.

Keywords: autism, central coherence, theory of mind, executive functioning, autistic symptomatology

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There is growing consensus among researchers of the need to invoke several co-existing cognitive capabilities/deficits in order to account for the extant heterogeneity in autism, evident at the genetic, neurobiological, and behavioral levels (Bailey & Parr, 2003; Dawson et al., 2002; Frith, 2003; Happé, 2003; Volkmar, Lord, Bailey, Schultz, & Klin, 2004). Abnormal cognitive functioning in persons with autism has been reported largely within the domains of theory of mind (ToM), executive functioning (EF) and central coherence (CC). There has, however, been little research examining functioning across these areas of cognition in the same sample. Furthermore, few studies have investigated the extent to which individual differences in these cognitive capabilities/deficits are related to behavioral symptomatology. We report a study that assessed several cognitive capabilities/deficits and their relationships to symptom severity in the context of an investigation with a primary focus on 'weak' CC. We examine the 'coherence' of the CC construct at the visuospatial level in a group of young children with autism, but also the nature and extent of its putative links with other cognitive deficits in ToM and EF. Furthermore, we examine whether individual variation in these three domains is associated with the core behavioral symptoms of autism.

Autism is characterised by severe deficits in reciprocal social interaction, verbal and nonverbal communication, and behavioral flexibility. Recent research, motivated largely by weak CC theory, has also focused on the preserved or superior areas of skill present in individuals with autism. Persons with autism have an uneven IQ profile, with good performance on subtests such as Block Design (Happé, 1994; Tymchuk, Simmons, & Neafsey, 1977); they are more accurate at locating embedded figures (Shah & Frith, 1983), and often show excellent rote memory. In order to account for the weaknesses and strengths associated with autism, Frith and Happé (1994) propose that individuals with autism and typically developing individuals are separated on a continuum that represents the extent to which the person strives for coherence. Purportedly, typically developing individuals display a natural propensity to process stimuli as Gestalts, whilst individuals with autism exhibit ‘weak’ CC, a preference for processing parts instead of wholes, at the expense of higher-level meaning.

Weak CC theory aptly explains the superiority of individuals with autism, relative to comparison children, on tasks where a local processing bias is beneficial, such as the Embedded Figures Test (EFT; Witkin, Oltman, Raskin, & Karp, 1971; Shah & Frith, 1983) and the Block Design task (Happé, 1994; Shah & Frith, 1993), the Navon task (Plaisted, Swettenham, & Rees, 1999; Rinehart, Bradshaw, Moss, Brereton, & Tonge, 2000), and on drawing tasks (Jolliffe & Baron-Cohen, 1997; Mottron & Belleville, 1993; Prior & Hoffman, 1990; Ropar & Mitchell, 2001). Similarly, CC theory accounts for relatively poor performance by those with autism when integration of information in context is required. For example, compared with matched comparison children, persons with autism fail to benefit from canonical patterns in dot counting (Jarrold & Russell, 1997) and have difficulty conceptually integrating the fragments of an object on an identification task (Jolliffe & Baron-Cohen, 2001).

However, there have been a number of contradictory findings concerning the nature of the coherence bias in autism. First, several studies have failed to demonstrate superior performance by persons with autism on various tasks expected to favor local processing (e.g., Brian & Bryson, 1996; Mottron, Burack, Stauder, & Robaey, 1999; Ozonoff et al., 1991; Rodgers, 2000). Second, whereas weak CC theory links superior parts-based processing in autism to limited holistic processing, recent research has not confirmed this limitation. Such studies have found that while children with autism demonstrated superior performance on tasks that benefited from a local approach, the autism and typically developing groups performed similarly on tasks that relied heavily on integrative processing. (Mottron, Burack, Iarocci, Belleville, & Enns, 2003; Plaisted, Saksida, Alcántara, & Weisblatt, 2003). However, these findings are at odds with other research reporting disrupted integrative processing in autism (e.g., Jarrold & Russell, 1997; Jolliffe & Baron-Cohen, 2001).

Finally, it is unclear whether performance on CC tasks is mediated by an underlying mechanism of coherence, as Frith and Happé (1994) claim. The notion of CC as a cognitive style has been investigated in typically developing children (Pellicano, Maybery, & Durkin, in press). Contrary to expectations, Pellicano et al. found that individual differences in preschoolers' performance on tasks purported to tap visuospatial coherence were not reliably interrelated in ways predicted by CC theory. Nevertheless, although little support was obtained for CC operating as a general cognitive style in typically developing children, it is still reasonable to expect that a (weak) coherence mechanism might underlie performance on visuospatial coherence measures in children with autism. The current study sought to investigate the validity of the CC construct in a group of young children with autism. In particular, we examine whether individual differences on several visuospatial coherence tasks could be explained by an underlying mechanism of coherence, and whether the relationship between local and global processing is reciprocal in nature.

Weak CC and other cognitive theories

An important question is the nature and extent of the relationship, if any, between weak CC and deficits in other cognitive domains. Both Frith (2003) and Happé (2003) favor the view that capabilities/deficits in weak CC are distinct from co-existing deficits in ToM and EF. Happé has reported evidence in support of the dissociation between weak CC and ToM abilities. She showed that weak CC, as indexed by superior Block Design performance (Happé, 1994) or impaired performance on a homograph task (Happé, 1997), was pervasive in autism, regardless of performance on ToM tasks. Also, a recent study of preschool children with autism and matched typically developing children showed no significant associations between putative precursors of ToM (joint attention and pretend play) and CC (as indexed by performance on the EFT and Pattern Construction, a task similar to Block Design) (Morgan, Maybery, & Durkin, 2003). Instead, Morgan et al. (2003) demonstrated that coherence bias, joint attention and verbal ability made independent contributions when discriminating between autism and comparison groups, suggesting that CC and ToM are unrelated domains of functioning in autism.

However, Baron-Cohen and Hammer (1997) found that fast times on the EFT were significantly related to poor performance on an advanced ToM test, prompting the authors to suggest that “weak CC may go hand in hand with impaired mindreading” (p. 550). Jarrold, Butler, Cottington, and Jiminez (2000) reported similar results using standard ToM (false belief) tasks and two CC measures (EFT and Pattern Construction) in a group of children with autism. Again, poor ToM ability was linked to a weak coherence bias (a relationship demonstrated after controlling for age and verbal ability). These findings indicate, contrary to Frith and Happé’s (1994) claims, that CC and ToM may in fact be related. Indeed, Jarrold and colleagues (2000) consider weak CC as a causal explanation of autism and speculate that this domain-general processing style might have a significant effect on inputs necessary for the development of a ToM.

Less attention has been directed towards the relationship between weak CC and executive dysfunction in autism. Both theories describe a domain-general information processing style/impairment, and some authors have suggested that notions of weak CC and executive deficits may overlap. On the one hand, Rinehart et al. (2000) suggested that difficulties in global processing might be a result of an inability to switch between the local and global aspects of a stimulus (see also Mottron, Belleville, & Ménard, 1999). On the other hand, Pennington et al. (1997) speculated that the executive dysfunction account could be subsumed by the weak CC account. Indeed, this is not dissimilar to arguments regarding ToM in autism, and how such deficits might be subsumed by the EF account of autism (e.g., Zelazo, Müller, Frye, & Marcovitch, 2003).

Only one study has empirically examined the possible link between CC and EF in autism. Booth, Charlton, Hughes, and Happé (2003) tested the drawing abilities of typically developing boys and two clinical groups of boys (autism spectrum disorder and ADHD), both of which present with difficulties in planning. Children were asked to draw a picture (e.g., a snowman) and to redraw it while inserting a new element to the drawing (e.g., teeth). Both clinical groups demonstrated planning problems, but only children with autism exhibited a detail-focused drawing style over and above their difficulties with planning. Furthermore, a piecemeal processing style on the drawing task did not predict planning problems in the clinical groups. These findings support Happé’s (2003) suggestion that cognitive capabilities/deficits might be separable in children with autism.

In a study of CC in typical development, Pellicano et al. (in press) found that individual differences in performance on coherence measures were unrelated to individual differences in ToM performance. However, contrary to predictions made by CC theory, aspects of CC (integrative processing) were significantly related to components of EF (particularly planning abilities), questioning whether CC is distinct from other domain-general processing systems such as executive control. In the context of these typical developmental patterns, in the present study, we assessed whether capabilities/deficits in CC were related to deficits in ToM and EF for children with an autism spectrum disorder (ASD).

Links to behavioral symptomatology

Although cognitive theories claim to account for some, if not all, behavioral symptoms of autism, few studies have examined the relationship between cognition and behavior. Those studies that have done so have reported mixed results. For example, ToM ability has been related to socio-communicative symptoms in some studies (Capps, Kehres, & Sigman, 1998), but not in others (Dawson, Meltzoff, Osterling, & Rinaldi, 1998). Executive deficits have been related to perseverative behavior in autism (Turner, 1997, 1999), but not to deficits in social interaction, communication and adaptive behavior (Liss et al., 2001). Joseph and Tager-Flusberg (2004) found that false belief understanding and planning ability were significantly related to communicative symptoms in children with autism, even when controlling for the effects of nonverbal mental age. However, the link between EF and communication was not significant when verbal ability was taken into account.

There have been only two studies, both by the same group, examining the relationships between performance on CC measures and levels of behavioral symptomatology. Teunisse, Cools, van Spaendonck, Aerts, and Berger (2001) assessed weak CC and cognitive set-shifting ability in a group of high-functioning adults with autism. Teunisse et al. reported little relationship between these cognitive domains and aspects of social functioning. In a longitudinal follow-up of the same individuals, Berger, Aerts, van Spaendonck, Cools, and Teunisse (2003) investigated whether weak CC and cognitive set-shifting ability were prognostic indicators. Cognitive set-shifting ability three years earlier significantly predicted social functioning; weak CC did not.

Both Frith (2003) and Happé (2003) describe the capabilities/deficits in CC, ToM and executive control as complementary. Each theory is purported to best capture some of the core symptoms of autism. Weak CC seems to account best for the perceptual and visuospatial anomalies associated with the disorder; executive dysfunction might directly relate to the nature and severity of the repetitive behaviors and stereotyped interests; a deficit in ToM might best encapsulate the lack of reciprocal social interaction and/or level of language abnormality. The links between the behavioral symptoms of autism and cognitive functioning across all three domains have yet to be investigated within the same sample of children with autism.

The present study

This study investigated cognitive functioning across several core domains in a reasonably large group of young children with ASD and a group of typically developing children, matched on chronological age, gender, verbal ability, and nonverbal ability. Four visuospatial coherence measures were administered: three of the coherence measures require local analysis, and the fourth relies heavily on integrative processing. In accord with weak CC theory, we expected that, compared with matched comparison children, children with ASD would show superior performance on the local tasks, but would fare worse on the integrative task. We also presented a battery of developmentally appropriate ToM tasks, assessing first- and second-order false belief, and EF tasks, designed to measure planning ability, set-shifting ability, and motor inhibition. The EF tasks were primarily chosen on the grounds that these widely used tests tap a range of EFs that appear reasonable a priori candidates for explaining aspects of performance on CC tasks. Consistent with previous findings (e.g., Hughes, 1996; Ozonoff et al., 1991), we expected that children with ASD would exhibit poor ToM ability, and poor executive control, compared to typically developing children. We further examined the pervasiveness of capabilities or deficits in each psychological domain by calculating the percentage of children with ASD who scored more than one standard deviation from the mean performance of the typically developing group for each cognitive measure. If indeed co-existing capabilities/deficits across the three cognitive domains can account for the development of autism, then we would expect that the resulting cognitive profile should be universal in children with ASD.

One of the primary objectives of this study was to assess Frith and Happé's (1994) notion of weak CC as a cognitive style in autism. Previous work has shown that CC is not a 'coherent' construct, at least in typical development (Pellicano et al., in press). We investigated whether weak CC was an autism-specific processing style by examining individual patterns of performance on CC tasks, once variation in chronological age, verbal ability and nonverbal ability had been taken into account. Previous studies have shown that effects of age and general ability can potentially mask relationships between more specific cognitive skills in samples with a wide range of abilities (e.g., Jarrold et al., 2000). After partialling out these influences, scores on the coherence measures should be highly interrelated (at least in the ASD group), if indeed performance on these measures is mediated by the positions children occupy on a single piecemeal-holistic processing-style continuum. If the coherence measures do tap a unitary construct, one additional expectation is that they should show redundancy in discriminating children with ASD from typically developing children.

The second objective was to establish the relationship between weak CC and co-occurring cognitive deficits in ToM and EF in children with ASD. Research findings have been equivocal with respect to the link between weak CC and poor ToM in ASD. According to Frith (2003) and Happé's (2003) most recent position, individual differences in performance on coherence measures should be unrelated to individual differences in performance on measures of ToM and executive control in the ASD group[2], when the effects of chronological age, verbal ability and nonverbal ability are taken into account. We also used discriminant function analysis to examine which cognitive capability or deficit could best predict ASD/ comparison group membership. If performance in the domain of CC is independent of ToM and EF, then variables tapping these latter two domains should add further to discriminating children in the clinical and comparison groups after controlling for CC variables. Alternatively, if performance on CC tasks is in some way related to performance on ToM and EF tasks (perhaps with CC being primary, and therefore mediating performance in the other domains), after the CC variables have been entered into the function, the ToM and EF variables should not add further to discriminating children with autism and comparison children.

Our final objective was to investigate the links between cognitive functioning and autistic symptomatology. This is a potentially informative approach, which has not been well utilized in the field. The Autism Diagnostic Interview – Revised version (ADI-R; Lord, Rutter, & Le Couteur, 1994) was chosen as a measure of symptom severity as it includes symptom scores in all domains (social interaction, communication, and repetitive behaviours) in its formal diagnostic algorithm. If capabilities/deficits in the three cognitive domains are responsible for the core impairments in autism, then we should expect significant correlations between task scores and domain scores on the ADI-R.

Method

Participants

Table 1 shows descriptive statistics for psychometric variables for all participants. Forty children (35 boys) with ASD aged 4-7 years were recruited through an autism register, various early intervention agencies, speech pathologists and support groups. Children had been diagnosed by experienced clinicians according to DSM-IV criteria (APA, 1994) and had a formal diagnosis of Autistic Disorder (N = 30) or Pervasive Developmental Disorder – Not Otherwise Specified (PDD-NOS; N = 10). Diagnosis was verified using the ADI-R (Lord et al., 1994), administered by a trained clinician (A.M.). Children either met full ADI-R criteria for autism (N = 33) or scored above the cut-off in at least 2 of the 3 domains (N = 7).[3] Children were excluded from participation if they had a comorbid medical (e.g., epilepsy) or neurodevelopmental (e.g., ADHD) diagnosis, a disorder with a genetic basis (e.g., Fragile X) or a verbal or nonverbal IQ below 80, as assessed by the Peabody Picture Vocabulary Test – Third Edition (PPVT-III; Dunn & Dunn, 1997) and the Leiter International Performance Scale – Revised version (Leiter-R; Roid & Miller, 1997), respectively (see Table 1).

A comparison group comprised of 40 typically developing children (31 boys) aged 4-7 years was recruited from several schools in suburban areas. Children were excluded from the group if they had any clinically significant impairment or diagnosis, such as ADHD. Parents of typically developing children completed the lifetime version of the Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003). The SCQ is a screening tool for autism, which comprises 40 items derived from the ADI-R. All children in the comparison group fell below the cut-off score of 15 specified by Rutter et al. (M = 4.30, SD = 3.52), suggesting that the typically developing children assessed here showed few behavioral symptoms of autism.[4]

The two groups were closely matched in terms of age, t (78) = .58, p = .56, verbal IQ, t (78) = .91, p = .37, nonverbal IQ, t (78) = .33, p = .74, and gender composition.

Insert Table 1 about here

Measures of verbal and nonverbal ability

The Peabody Picture Vocabulary Test – Third Edition (PPVT-III; Dunn & Dunn, 1997) assesses receptive vocabulary and was used here as a measure of verbal ability. While it is acknowledged that the PPVT may overestimate general verbal ability in children with ASD (Mottron, 2004), we used it here in an effort to avoid underestimating verbal ability due to possible limitations in expressive abilities, as might be the case with the verbal subscales of the Weschler scales or the Differential Ability Scales. The Leiter-International Performance Scale – Revised (Leiter-R; Roid & Miller, 1997) was used to measure nonverbal ability. We chose to use the Leiter-R over the nonverbal subtests of the Wechsler scales of intelligence because some of the subtests (Block Design and Object Assembly) are similar to the CC tasks used in this study. Four subtests from the Leiter-R were used to estimate nonverbal ability: Matching, Associated Pairs, Forward Memory, and Attention Sustained.[5] Raw scores from the PPVT-III and the Leiter-R are reported and used in statistical analyses as these scores reflect both developmental and individual differences in verbal and nonverbal ability.

Central Coherence (CC) measures

Embedded Figures Tests (EFT). Both the Preschool version of the EFT (PEFT; Coates, 1972) and the triangle set of the Children's version of the EFT (CEFT; Witkin et al., 1971) were administered due to the age range of the participants. For each trial of the PEFT, children were shown a picture of a triangle and then asked to find the same triangle in a larger black and white meaningful figure as quickly as they could. Children completed 3 practice and 24 test trials. For the CEFT, children were shown a cardboard cut-out of a triangle and asked to quickly locate the same triangle in a larger coloured picture. Children were given 4 demonstration, 2 practice and 11 test trials. Response latencies (in seconds) seem to be more sensitive than accuracy (Jarrold et al., 2000), and were recorded for all trials. For both versions of the EFT, if the child failed to identify the hidden triangle within 30 s, she/he was given a maximum score of 30 s for that trial. Six trials of the PEFT did overlap with 6 trials from the

CEFT; therefore, order of administration of the PEFT and CEFT was counterbalanced across participants.

Pattern Construction Task from the Differential Ability Scales (Elliott, 1990). The Pattern Construction subtest is very similar to the Block Design task from the Wechsler Pre-Primary Scales of Intelligence – Revised (WPPSI-R; Wechsler, 1989), but contains a larger range of items (2-, 4-, and 9-block patterns), and can be used for a wider age range (3 - 17 years). Children were required to produce patterns using three-dimensional blocks whose surfaces are yellow, black, or half-yellow and half-black, to match a two-dimensional model. The test yields a composite score, based on both accuracy and speed.

Figure-Ground Task from the Developmental Test of Visual Perception – Second Edition (Hammill, Pearson, & Voress, 1993). Children were shown several different shapes (e.g., triangles, squares, circles) and were required to identify as many of the shapes as they could, where the shapes were embedded in a complex background. A score of 1 was awarded for every trial in which all of the hidden figures were located (maximum score of 18).

Developmental Test of Visual-Motor Integration (Beery, 1997). The normed VMI test requires children to copy 24 drawings, which begin as simple shapes and move on to more complex integrated shapes. To obtain a score of 1 on any given trial, children needed to maintain the overall configuration of the figure they were copying, ensuring that the spatial relationships between the parts were preserved (maximum score of 24).

Theory of Mind (ToM) measures

First-order False-belief. Six stories involved child protagonists performing Unexpected Transfer scenarios similar to Baron-Cohen, Leslie, and Frith’s (1985) Sally-Ann task. These were presented to participants via a CD-ROM. Three additional scenarios were presented, modelled on Perner, Leekam and Wimmer’s (1987) Unexpected Contents task, each including an own belief and other belief test question (see Appendix A for details of these tasks). For both first-order tasks, children were required to predict the protagonist’s behavior based on his/her attributed false belief. Children received a score of 1 for correctly answering each belief question (total score out of 12).

Second-order False belief. This task involved two scenarios of an unexpected transfer similar to Perner and Wimmer's (1985) task (see Appendix A), presented via CD-ROM. This advanced test of ToM required the child to attribute a mistaken belief about a belief to a character. Children were given a score of 1 for correctly answering each belief question (total score out of 2).

Executive Function (EF) measures

Luria's handgame. Following Hughes (1996), the task began by asking the child to point his/her index finger, and to form a fist, to ensure that he/she could copy the experimenter. In the Imitation condition, the child was told: "First we both put our hands behind our backs; now when I show my hand I want you to make the same shape as me. So if I make a fist, you make a fist, and if I point a finger you point a finger (p. 231)." Children scored 1 point for each correctly imitated trial (out of 10). In the Conflict condition, the child was instructed to perform the opposite action: "Now, if I point a finger, I want you to show a fist, and if I show a fist I want you to point a finger, so we're not making the same shapes. What do you do if I show a fist? … and if I point a finger? (p. 231)" Again, children were given 1 point for successful completion of each conflict trial (out of 10). Feedback was provided after each trial. The 5 fist and 5 finger trials in each condition were presented in a randomized order, and the order of presentation of conditions was counterbalanced across participants. High scores on the Conflict condition reflect good inhibitory processes.

Mazes Task. This task (taken from the WPPSI-R; Wechsler, 1989) required children to complete a series of progressively more complex mazes. Children needed to plan their route ahead, in order to reach the opening of the maze whilst making minimal errors. An error was scored as any instance where the child deviated from the correct path. Success was determined by the number of errors made in each maze. Testing discontinued if children failed 2 consecutive mazes (i.e., completed the mazes, but with numerous errors). High scores indicate good planning ability (maximum score of 26).

Tower of London. The Tower of London (Shallice, 1982), is a task of higher-order planning. Our version consisted of 3 vertical pegs of differing lengths and 3 beads coloured red, black, and white. There were 16 problems in total, divided into 4 levels of increasing difficulty according to the number of moves required to achieve the goal state. The first 4 problems (1-move) involved minimal planning. Children were then given 4 problems in each of the following problem sets: 2-move, 3-move and 4-move. They were shown a picture of the Tower of London puzzle displaying the beads in a desired end-state. They were required to move the pegs on their own apparatus from a prearranged start-state to match the goal state using as few moves as possible. Instructions stressed moving only one bead at a time and not placing any beads on the table. If a child failed all of the problems in a single problem set, testing ceased. The number of problems solved within the minimum number of moves was recorded (maximum score of 16). High scores reflect good planning ability.

Set-shifting Task. This task was originally developed by Hughes (1998) and is a developmentally appropriate version of the Wisconsin Card Sorting Task. It is a measure of flexibility and requires children to switch cognitive set in response to verbal feedback. Children were shown 1 of 3 decks of cards – the cards in each deck differed on three dimensions: (1) colour (green vs. pink, blue vs. red, or yellow vs. purple); (2) picture shown (hearts vs. diamonds, squares vs. moons, or stars vs. happy faces); (3) and size of picture (small vs. large). Children were told that they were to work out which cards were the teddy’s favorite cards. If the card was one of teddy’s favorites, the child was to post it into a postbox. Alternatively, if the card was not one of teddy’s favorites, then the child turned the card facedown on the table. Feedback was provided after each trial. Three rules were used (colour, shape, size), the order of which was counterbalanced across participants. The sorting rule changed either when the child had successfully sorted 6 cards consecutively, or when a maximum of 20 trials had been presented. Importantly, children were not told that the sorting rule had changed; nonetheless, this was implicit in the fact that the child was presented with a new teddy and new deck of cards. Set-shifting performance was rated by the total number of trials to criterion on all three rules (out of 60). A low score (i.e., minimal cards needed to identify the sorting rule) indicates good cognitive flexibility.

Symptom Severity

We used the ADI-R (Lord et al., 1994) to measure symptom severity in the ASD group. The ADI-R is a standardised, caregiver interview for use in the differential diagnosis of pervasive developmental disorders and autism, as defined by the DSM-IV (APA, 1994) and ICD-10 (WHO, 1993). The ADI-R assesses three primary areas: (1) quality of reciprocal social interaction; (2) communication and language; and (3) restricted and repetitive, stereotyped interests and behaviors. An algorithm is used to calculate a total score within each domain, using predominantly items that focus on the 4 to 5 year age range, when symptoms are most pronounced. This algorithm was used to confirm children's clinical diagnosis. To examine relationships between cognitive capabilities/deficits and autistic symptomatology, the ADI-R algorithm was re-run using current scores to provide information regarding the child's current functioning in the three ADI-R domains (social interaction, communication, repetitive behaviors).

General Procedure

Children were seen individually by the principal investigator in a quiet room, either at home or at school. All measures were administered in two 1 h visits, approximately 1-2 weeks apart. Breaks were included to ensure that children remained motivated throughout each session. Measures of verbal and nonverbal ability were always administered first. The order of presentation of the remaining tasks was randomised across participants.

Results

Preliminary analyses

Table 2 shows descriptive statistics on all measures for each group. Preliminary analysis indicated that most of the data met assumptions of normality; however, performance was at ceiling across groups for the Imitation condition of Luria's handgame. This was not a crucial condition, and so was not analysed further. The data were screened for outliers more extreme than 3 SD from the mean. One child with ASD scored more than 3 SD above the mean on the Pattern Construction task and one typically developing child scored more than 3 SD above the mean on the Mazes task; however, results of analyses did not change with the exclusion of these outliers, and therefore analyses are reported on the full data set. Analyses of variance (ANOVAs) are typically reported for group comparisons; nonparametric tests are reported where assumptions concerning heterogeneity of variance were questionable. Reliability of measures was also assessed where possible.

Insert Table 2 about here

Relationships of cognitive variables to age and general ability variables. For both groups, correlational analyses revealed significant relationships between most cognitive variables and chronological age, verbal ability and nonverbal ability (see Table 3), although there were some exceptions. Correlations between age and EFT time, Pattern Construction scores, Figure-Ground scores, or ToM scores were not significantly correlated in the ASD group, and nor were significant associations observed between verbal ability and EFT times or Figure-Ground scores. Set-shifting scores were unrelated to age or nonverbal ability in the comparison group, and the correlations between age or verbal ability and Figure-Ground scores were also nonsigificant.

Insert Table 3 about here

Group differences on cognitive tasks across domains

To begin, we created a composite score of the EFTs by averaging the mean times for the two tasks (EFT time).[7] This was well-justified by the facts that there were no effects of presentation order for the two EFTs, and mean response times for the PEFT and CEFT correlated highly, r (80) = .89, $p < .001$. ANOVAs revealed significant differences between children with ASD and matched comparison children on all CC variables (see Table 2). Compared with typically developing children, children with ASD obtained significantly faster times on the EFT, F (1, 78) = 135.16, $p < .001$, $\eta_p^2 = .63$, higher scores on the Pattern Construction subtest, F (1, 78) = 61.07, $p < .001$, $\eta_p^2 = .44$, and the Figure-Ground task, F (1, 78) = 94.34, $p < .001$, $\eta_p^2 = .55$, and lower scores on the VMI task, F (1, 78) = 7.51, $p < .01$, $\eta_p^2 = .09$.

Non-parametric Mann-Whitney U tests revealed that, as expected, children with ASD performed significantly worse than typically developing children on each of the three ToM measures (largest U = 1489.50, all ps < .05). Spearman rank-order correlations showed that the three ToM scores were significantly correlated within each group (range of r_s = .41 - .77, all ps < .005). Accordingly, to simplify further analyses, we calculated a total ToM score by summing performance across tasks (total score out of 14). Internal consistency for the 14 test questions was high (Cronbach’s alpha = .89). An ANOVA confirmed that the children with ASD obtained significantly lower ToM composite scores than their typically developing counterparts, F (1, 78) = 20.45, $p < .001$, $\eta_p^2 = .21$.

Children with ASD also performed significantly worse than comparison children on Luria’s handgame (Conflict condition), F (1, 78) = 9.11, $p < .005$, $\eta_p^2 = .10$, the Tower of London task, F (1, 78) = 19.58, $p < .001$, $\eta_p^2 = .20$, and the Set-shifting task, F (1, 78) = 15.43, $p < .001$, $\eta_p^2 = .16$, but not on the Mazes task, F (1, 78) = 1.38, ns.

Universality. To assess the prevalence of these capabilities/deficits in ASD, we examined the percentage of children with ASD whose scores fell more than 1 SD from the mean of the typically developing group on each cognitive variable. For CC tasks, we found that fast times on the EFT were present in 92% of children with ASD, whilst 78%, and 92% of children with ASD performed at least 1 SD above the mean of the typically developing group on the Pattern Construction and Figure-Ground tasks, respectively. Only 35% of children with ASD performed worse than 1 SD below the comparison group mean on the VMI task.

Examining performance on ToM tasks, we found that 68% of children with ASD performed 1 or more SD below the mean of the typically developing group. For performance on EF measures, the percentage of children with ASD who fell at least 1 SD below the mean of the typically developing group was 38% for Luria's handgame, 28% for the Mazes task, 48% for the Tower of London task, and 55% for the Set-shifting task.

CC as a cognitive style

CC theory predicts that there should be natural variation among individuals in the extent of their coherence bias, and that autism simply reflects the weak end of this distribution. Previous findings (Pellicano et al., in press), however, provide little support for this continuum of coherence within a typically developing sample of children, and therefore all correlational analyses were performed within each group separately. Table 4 presents the intercorrelations of interest. To reiterate, we operationalised weak CC as low times on the EFT, high scores on the Pattern Construction task, high scores on the Figure-Ground task, and low scores on the VMI task. If weak CC were an underlying factor that varies within children with autism, then CC variables should be intercorrelated in ways that would reflect this cognitive bias.

Insert Table 4 about here

In the ASD group, we found that most of the CC variables were significantly interrelated. As predicted, time taken on the EFT was negatively associated with Pattern Construction and Figure-Ground scores, and the Pattern Construction and Figure-Ground scores were positively correlated. However, Pattern Construction scores were also positively correlated with VMI scores. The direction of this latter correlation is contrary to expectations based on CC theory, but is in line with findings from a previous study (Pellicano et al., in press), where it was argued that these two tasks may be positively related due to their shared demands on visuospatial integration. (Note that whereas segmentation of the pattern may be a critical component of Pattern Construction performance, combining blocks to form the pattern is also a necessary component.) In order to determine how much of the relationship between CC measures was due to the effects of chronological age, verbal ability and nonverbal ability, partial correlations were run with these developmental variables as the covariates. With age partialled out, a similar pattern of correlations emerged, with the exception of the Pattern Construction and VMI correlation, which was no longer significant. When age, verbal ability and nonverbal ability were partialled out, only a negative correlation between EFT time and Pattern Construction scores remained significant (albeit weak).

For the typically developing group, the raw correlations between CC variables were of a similar pattern to that of the ASD group, although the correlations were a little more substantial, and generally confirmed previous findings (Pellicano et al., in press). When age was adjusted for, most of the associations dropped to nonsignificance, apart from the positive correlation between Pattern Construction and VMI task scores. This pattern of results was upheld when the effects of age, verbal ability and nonverbal ability were accounted for.

Relationships between weak CC and deficits in ToM and EF

CC and ToM. Frith (2003) and Happé (2003) argue that CC and ToM are independent functions in children with and without ASD, but, as noted in the Introduction, findings have been mixed (Jarrold et al., 2000; Pellicano et al., in press). It is still possible that these functions are unrelated in typically developing individuals but might represent related domains in autism. Within-group correlations between CC and ToM measures are presented in Table 5. In the ASD group, ToM scores were significantly and positively associated with scores on the Pattern Construction, Figure-Ground and VMI tasks. These correlations remained significant when age was partialled out, but all correlations dropped to nonsignificance when age, verbal ability and nonverbal ability were adjusted for.

A similar pattern of results was found in the typically developing group; all CC variables (with the exception of Figure-Ground scores) were initially correlated with ToM scores. Once again, when general and individual differences were partialled out of these relationships, the correlations were no longer significant. With the exception of the VMI-ToM correlations, these results are contrary to what Jarrold et al. (2000) would have predicted; that is, that weak CC (reflected in better local processing) would be associated with poor ToM skills after controlling for general sources of individual and developmental differences. Note that the significant raw correlations of ToM scores with the Pattern Construction, Figure-Ground and EFT variables are in the direction of better ToM performance being associated with weak CC, and so are contrary to previous findings (Baron-Cohen & Hammer, 1997; Jarrold et al., 2000).

Insert Table 5 about here

CC and executive control. According to Frith (2003) and Happé (2003), abnormalities in CC and EF are dissociable in children with ASD. However, some researchers suggest that the two constructs might overlap, and previous findings suggest that good executive control is related to good integrative ability (as indexed by good Pattern Construction and VMI task performance) in typically developing preschoolers (Pellicano et al., in press). Intercorrelations between CC and EF variables are presented in Table 5. Generally, good performance on the Pattern Construction, Figure-Ground and VMI tasks was related to better scores on EF tasks in the ASD group. Fast times on the EFT, however, were only significantly associated with high scores on the Tower of London task. These correlations generally remained significant when the effects of age were partialled out; however, when age, verbal ability, and nonverbal ability were all partialled out, the only significant correlations involved VMI scores coupled with scores from Luria’s handgame and the Mazes and Set-shifting tasks.

In the typically developing group, there were significant relationships between most CC and EF variables. The exception was Set-Shifting scores, which were unrelated to any CC variables. When all general and developmental differences were taken into account, we found that only the Pattern Construction scores remained significantly correlated with planning ability on the Mazes task (similar to Pellicano et al., in press).

Discriminating the groups. A stepwise discriminant function analysis was carried out to determine if variables from the three cognitive domains accurately predicted group membership (ASD, typical development). All potential predictors were included together. A stepwise approach allows those variables that are most predictive to enter the function first. The variables that entered the discriminant model were: EFT time, VMI, Figure-Ground, ToM, Pattern Construction, and Tower of London scores (see Table 6). Chronological age, verbal ability, nonverbal ability, Luria’s handgame, Mazes, and Set-shifting scores failed to enter the model. Chi-squared analysis showed a strong relationship between the group variable and the predictors, χ^2 (6) = 139.33, $p < .001$ (Wilks’ lambda = .156). The canonical R^2 associated with the model was .92, and the discriminant function analysis correctly classified 99% of cases. Only one clinical case was misclassified.

Hierarchical analyses were also performed to control the order in which the six successful predictors (listed in Table 6) were entered into the discriminant function. When each predictor was added last to the function, it significantly improved the discrimination of the two groups (see Table 6). The exception to this was the VMI measure, which failed to make an independent contribution when added last to the function.

Insert Table 6 about here

Relationships between cognitive capabilities/deficits and behavioral symptomatology. To examine links between cognitive capabilities/deficits and concurrent behavioral symptoms, we conducted correlational analyses between cognitive variables and domain (current) scores of the ADI-R. It was expected that weak CC, poor ToM and poor executive control would be related to higher scores in each ADI-R symptom domain. Contrary to predictions, all cognitive variables failed to correlate significantly with ADI-R domain scores (all $ps > .05$). Following Joseph and Tager-Flusberg (2004), we tried controlling for verbal ability using partial correlations to examine relations between cognitive variables and ADI-R domains. All correlations were nonsignificant (all $ps > .05$). One could argue that symptom scores for 4-5 years should have been used in analyses, as these might have better represented the ‘pre intervention’ behaviors of the child, yielding closer relationships with cognitive variables (which may be less influenced by the effects of intervention). However, subsequent correlational analyses between cognitive functioning and symptom scores based on reported behavior at 4-5 years also yielded few significant relationships. This analysis revealed a significant negative correlation between EFT time and scores on the social domain, r (80) = -.41, $p = .01$; this correlation, however, failed to survive Bonferroni correction.

Discussion

The overarching aim of this study was to assess co-occurring capabilities/deficits in three core cognitive domains in young children with ASD, with particular emphasis on the notion of weak CC. Additional aims were to: (1) elucidate the nature of weak CC in young children with ASD both at the group level and with respect to individual patterns of performance; (2) determine the extent of the relationship, if any, between weak CC and co-existing deficits in ToM and executive control; and, (3) assess the associations between capabilities or deficits in key cognitive domains and behavioral symptoms of autism.

Multiple cognitive capabilities/deficits in ASD

The limitations of cognitive theories that attempt to explain autism in terms of a single primary deficit has forced researchers to consider a less parsimonious, but perhaps more plausible, multiple capabilities/deficits view to explain the development of autism. This study confirmed the presence of multiple capabilities/deficits across several cognitive domains. With respect to weak CC, children with ASD outperformed typically developing children on those tasks where a local processing bias was beneficial (the EFT, Pattern Cons truction and Figure-Ground tasks). These findings are consistent with previous studies, which have also demonstrated superior performance in autism on disembedding tasks (Baron-Cohen & Hammer, 1997; Morgan et al., 2003; Ropar & Mitchell, 2001; Shah & Frith, 1983; but see Brian & Bryson, 1997) and on block construction tasks (Happé, 1994; Morgan et al., 2003; Ropar & Mitchell, 2001). In contrast, compared with typically developing children, children with ASD underperformed on the VMI task, which placed demands on global processing. This is also in line with predictions made by weak CC theory, where a complementary relationship is purported to exist between local and global processing (Frith & Happé, 1994). Furthermore, children with ASD performed worse on all ToM tasks compared with comparison children. Consistent with previous studies (e.g., Hughes, 1996; Ozonoff et al., 1991), children with ASD also performed worse on the Tower of London task, the Set-shifting task and Luria’s handgame, compared with their typically developing peers, providing evidence of difficulties in higher-order planning, cognitive flexibility and motor inhibition in autism.

Remarkably, exceptional performance on local processing tasks was present in most children with ASD. In contrast, difficulties with integration were present only in a modest proportion (35%) of children with ASD. This is similar to findings from Jarrold and Russell (1997), who report that approximately half of their ASD sample exhibited a weak coherence bias, as indexed by the failure to use canonical patterns to augment counting speed. These results in combination suggested that concomitant difficulties in global or integrative processing might not be characteristic of all children with ASD. Indeed, other studies have also reported limited evidence of impaired global processing in autism (Mottron et al., 2003; Plaisted et al., 2003).

Weaknesses in ToM and EF were found to be less pervasive than abnormalities in CC in young children with ASD. In line with earlier estimates (Ozonoff et al., 1991; see also Yirmiya, Erel, Shaked, & Solomenica-Levi, 1998), poor performance on false belief tasks only accounted for 68% of children with ASD, suggesting that poor ToM is not universal in autism.[9] Meanwhile, executive deficits characterised, at most, only half of our sample of children with ASD. These results are in contrast to results from Ozonoff et al. (1991), who found pervasive impairments on tasks of EF in their sample of high-functioning individuals with autism. However, Ozonoff et al. (1991) employed a liberal criterion to examine universality of deficits in autism (percentage of children with autism scoring below the mean performance of the comparison group), which probably explains the discrepancy between our results and theirs.

The results of the discriminant function analysis confirmed that capabilities/deficits in each core domain are necessary to successfully predict ASD/ comparison group membership. In fact, six predictors entered the function: time taken on the EFT, the VMI and Figure-Ground tasks, ToM performance, Pattern Construction task, and Tower of London scores. Remarkably, the function was able to successfully classify 99% of cases. The analysis further showed that each of these variables made a significant contribution when added last to the function (with the exception of the VMI task), indicating that each variable provided unique variance in discriminating the groups. This finding seems to be at odds with the findings regarding universality of capabilities/deficits, which demonstrated that weak CC, rather than ToM or EF difficulties, accounted for the majority of children with ASD. It is important to note, however, that the ASD and control groups were not entirely separated on CC scores, and so for that reason, ToM and EF variables were able to add significantly to the discrimination of the groups.

There are several points one must bear in mind when interpreting the results regarding universality of capabilities/deficits in ASD. Firstly, we are unable to assume that the underlying processes and/or mechanisms used to succeed on ToM and EF tasks are necessarily the same for children with and without ASD. Indeed, while some children with ASD do achieve success on ToM tasks, it is not clear that they do so because they possess the ability to 'mentalize' as such (Frith, Morton, & Leslie, 1991). Our data are silent as to whether those children who passed ToM tasks (and EF tasks) in this study did so by utilizing strategies similar to those used by typically developing children. Secondly, comparing the relative strength of group differences across measurement domains may be problematic for psychometric reasons. The EFT, Figure-Ground and Pattern Construction measures are reported to have good reliability, and our composite ToM variable also yielded a high reliability estimate, consistent with Hughes et al. (2000). Evidence of atypical performance in the ASD group was most pronounced for these variables. It is possible that lower reliability contributed to our inability to find evidence of pervasive EF deficits in the ASD group, as low reliability has been reported for tasks such as the Tower of Hanoi (e.g., Bishop, Aamodt-Leeper, Creswell, McGurk, & Skuse, 2002). Thus, we must be cautious when interpreting the universality results, as differences in effect sizes across domains could be related to variation in the reliability of measurement.[10]

Thirdly, analyses of universality might depend on the developmental functions for each cognitive capability. If these functions are not parallel for ASD and typically developing children, a substantial group difference evident at one point in development might be curtailed at other points in development. The cross-sectional nature of this study and restricted age range of the sample prevented us from fully examining the issue of development here. However, our reasonably large samples of children permitted the inclusion of chronological age (younger, older) as an additional 'blocking' factor (see Maxwell & Delaney, 2004) in two-way ANOVAs on scores on cognitive measures. For the majority of cognitive variables, no significant group x age interaction effects were found, suggesting similar developmental pathways for the two groups. For two variables, however, this was not the case. Superiority in Pattern Construction performance in the ASD group was more evident in younger children (ASD: M = 130.83, SD = 13.33; typical development: M = 96.68, SD = 10.43) than in older children (ASD: M = 133.86, SD = 16.61; typical development: M = 115.72, SD = 9.38). For ToM, the greatest impairments in the ASD group were demonstrated for children in the older subgroup (ASD: M = 4.41, SD = 3.91; typical development: M = 10.33, SD = 3.16) compared with the younger subgroup (ASD: M = 3.89, SD = 3.37; typical development: M = 6.62, SD = 3.57). It could be that superior local processing (at least performance on the Pattern Construction task) is more indicative of children's development in the early stages of autism, but that deficits in ToM become more central to autism later in development. Certainly, this highlights the importance of understanding the profile of strengths/weaknesses in performance in the context of the child's developmental level (see Burack et al., 2002). Future research will need to chart the developmental trajectory of each capability/deficit in autism to establish whether such capabilities/deficits are present at the very onset of autism, or whether they emerge later in development.

Weak CC: A cognitive style?

One primary aim of this study was to further elaborate the construct of (weak) CC in ASD. The notion of CC as a cognitive style was investigated by examining individual patterns of performance on visuospatial coherence measures, and the unique contributions made by CC measures to discriminating between ASD and comparison groups. The raw correlations initially revealed significant associations between most CC task scores in the ASD and typically developing groups. Most of these relationships disappeared when the effects of age, verbal ability and nonverbal ability were partialled out. The exception to this was the relationship between the EFT and Pattern Construction scores, which remained significantly (yet weakly) correlated for the ASD group. The results from the discriminant function analysis confirmed this finding: each CC measure contributed unique variance to distinguishing between ASD and typically developing children (with the exception of the VMI variable).

These results conflict with previous studies (Jarrold et al., 2000; Ropar & Mitchell, 2001) that report substantial correlation coefficients between scores on tasks tapping visuospatial coherence in autism. One possible explanation for the discrepancy between these findings relates to variation in nonverbal ability in the ASD group. Neither Jarrold et al. (2000) nor Ropar and Mitchell (2001) partialled out the effects of nonverbal ability from relationships between coherence task scores (as nonverbal ability was not measured as part of these studies), and this might have contributed to differences in the magnitudes of correlation coefficients across studies.

A further possibility concerns the VMI task in particular. Although this task requires representing the relationships between parts of the to-be-copied stimuli, it also places considerable demands on fine-motor skills. Motor coordination difficulties (e.g., poor handwriting) have been reported in children with high-functioning autism (Beversdorf et al., 2001); therefore, it is possible that individual differences in VMI task performance reflect individual differences in motor coordination to some extent. This might partly explain the lack of significant correlations between the VMI measure and other coherence measures in the ASD group. However, it is unlikely that the poor performance of the ASD children on the VMI task is attributable to motor coordination difficulties exclusively, given that the ASD children performed similarly to comparison children on the Mazes task, another measure which requires intact fine-motor coordination.

What do our findings mean for CC theory? At the group level, it would seem that the theory's predictions are borne out: children with ASD do well on tasks where a local processing bias is advantageous, but perform poorly on tasks requiring integrative processing, compared with their typically developing peers of similar age, gender, and ability. However, when we look at patterns of individual performance on coherence measures, we find little evidence to suggest that performance indicates an underlying continuum that reflects a reciprocal relationship between piecemeal and holistic processing. It is difficult to reconcile the consistent evidence favoring weak CC in autism at the group level, with the absence of consistent relationships among CC variables at the level of individual differences. Most studies use a group comparison design when examining capabilities or deficits in individuals with ASD, matching groups either on age, verbal ability and/or nonverbal ability. Our findings highlight the importance of also examining within-group patterns of performance on cognitive tasks.

These findings for children with ASD corroborate earlier results from a study examining weak CC in typically developing preschoolers, which also failed to find evidence for a single factor of coherence uniting individual differences in performance across the tasks (Pellicano et al., in press). Indeed, relationships between coherence measures could not be established independently of the variation in CC scores explained by differences in age, verbal ability and nonverbal ability. In combination, these results lead us to cast doubt on Frith and Happé's (1994) notion of a 'continuum of coherence' – CC does not appear to be operating as a unitary cognitive style in either typically developing or ASD populations.

Weak CC: Links with ToM and executive control?

Frith (2003) and Happé (2003) maintain that weak CC is independent of ToM ability. Findings from both autism (Happé, 1994, 1997), and typical development (Pellicano et al., in press), have supported this view. However, some researchers have reported evidence for an inverse relationship between ToM and disembedding ability in adults (Baron-Cohen & Hammer, 1997), and in children (Jarrold et al., 2000) with autism. Jarrold et al. speculated that weak CC might be primary in autism, causing the atypical development of ToM. The results from the current investigation revealed significant raw correlations between false belief scores and most scores on tasks tapping CC. However, when the variance accounted for by age, verbal ability and nonverbal ability was removed, these relationships disappeared in the clinical and comparison groups, providing evidence for the independence of these psychological domains in both ASD and typical development. Part of the discrepancy between our results and the two reports of an inverse relationship between ToM and disembedding ability (Baron-Cohen & Hammer, 1997; Jarrold et al., 2000) could be because we partialled out variance attributable to nonverbal ability, in addition to variance attributable to age and verbal ability. Note that when we controlled just for age and verbal ability, the only significant correlation was consistent with a positive relationship between ToM skill and disembedding ability.

Contrary to predictions made by weak CC theory (and findings from Booth et al., 2003), we did find some reliable relationships between CC and EF measures. Scores on these measures, for the most part, were significantly intercorrelated, such that superior performance on the CC tasks was related to better planning, inhibition, and set-shifting abilities. Most of these correlations, however, did not hold up when variance shared with age, verbal ability and nonverbal ability was controlled. One exception was performance on the VMI task, which remained robustly related to performance on Luria’s handgame and the Mazes and Set-shifting tasks, indicating that better visuomotor integration was associated with better inhibition, planning, and cognitive flexibility. Interestingly, it was performance on the task involving global processing (on which children with ASD fared worse than comparison children), rather than on those requiring local processing, that was related to executive control. This corroborates findings with typically developing children (Pellicano et al., in press), consisting of relationships between integrative processing and some measures of executive control, particularly planning measures. Perhaps better executive abilities might assist performance on tasks necessitating the integration of information, by allowing one to hold concurrently in mind representations of parts and wholes, and to shift flexibly between these representations. Indeed, this is quite similar to conceptualizations of some aspects of EF, such as working memory (see Mottron et al., 1999). However, it is equally possible that relationships could occur in the opposite direction: that somehow good integrative ability facilitates performance on tasks requiring flexible, goal-oriented behavior. Clearly, the relationship between global processing and EF in autism is in need of further exploration.

Relationships to symptomatology

Surprisingly, we obtained scant evidence of reliable relationships between performance on cognitive tasks and reports of current symptoms. Given the relatively large sample of children with ASD assessed in the current investigation, and the use of a highly reliable and valid measure of autistic symptomatology, the ADI-R, it is somewhat puzzling how the cognitive variables in each domain were able to discriminate successfully between clinical and comparison groups, yet failed to relate to behavioral symptomatology. Nonetheless, these null findings are not unique; limited relations between cognitive measures and reports of behavioral symptoms have been reported elsewhere (e.g., Rumsey, Rapoport, & Sceery, 1985; Travis, Sigman, & Ruskin, 2001).

There may be two potential reasons for our negative findings. First, the type of information used to derive symptom severity scores from the ADI-R may have affected the results. During the interview, information is obtained about the child’s current behavior, and about his/her behavior at age 4-5, when symptoms are considered most pronounced. In this study, scores relating to current behavior were used in correlational analyses, as we reasoned that associations between cognitive variables and indices of behavioral symptoms would be more valid if we obtained concurrent assessments of both. However, the validity of the diagnostic algorithm for different ages has not been tested, and this may account for the lack of significant intercorrelations between cognition and behavior. It is also possible that, when asked about their child’s current functioning, parents tend to evaluate the child with respect to their progress since diagnosis, and therefore may underestimate the severity of their child’s everyday behavioral symptoms.

Second, our use of the ADI-R, a parent-report measure, may explain why our findings are incongruous with a recent study (Joseph & Tager-Flusberg, 2004), which found that communicative symptoms were inversely related to ToM and planning abilities (on a task similar to the Tower of London). Joseph and Tager-Flusberg used the Autism Diagnostic Observation Schedules (ADOS; Lord, Rutter, DiLavore, & Risi, 1999), where knowledge regarding symptom severity is gained via a structured observation of the child. It may be the case that direct observational measures provide the clearest picture of the child's current symptoms. However, using solely observational techniques to index symptom severity has its own problems; the child's behavior is observed only in a limited range of situations, which may decrease the sensitivity to detect infrequent but highly salient events that may be indicative of the child's severity.[12] Bishop and Norbury (2002) showed that diagnostic information obtained from caregiver interview and structured observational techniques, the ADI-R and the ADOS, respectively, were not always in agreement regarding the diagnosis of children with autism. This highlights the importance of obtaining information regarding symptom severity from multiple sources, including via parental interview <u>and</u> direct observational techniques, to ensure that investigators acquire a valid representation of the child's current symptomatology.

Establishing links between performance on cognitive tasks and everyday behavioral symptoms in autism is clearly a key challenge for future research. However, one must consider whether it is reasonable to expect one-to-one mapping between cognition and behaviour (see Karmiloff-Smith, Scerif, & Thomas, 2002). Although certain autistic symptoms persist throughout development, behaviors are likely to change over time. Similarly, a cognitive abnormality could manifest itself in several different ways across development. Therefore, the paucity of correlations between current ADI-R scores and cognitive variables might then reflect the possibility that there is no simple or direct relationship between current cognitive functioning and current behavioral symptoms.

In conclusion, our results provide partial support for the construct 'weak CC' at the visuospatial level in children with ASD. Children with ASD do seem to perform much better than typically developing children on tasks for which performance is favored by a facility in local processing, but are less adept compared to comparison children on a task requiring visuospatial integration, as Frith and Happé (1994) propose. However, our findings for the coherence measures in both children with and without ASD fail to confirm that a single processing style unites individual patterns of performance. Other analyses further revealed a profile of strengths and weaknesses for autism in CC, false belief understanding, and aspects of executive control, which are generally unrelated to each other and provide independent contributions to predicting group membership. Thus, our results support the emerging consensus: that there is not one deficit, but several core underlying capabilities/deficits that coexist in ASD. The particularly large sample of children with ASD studied here encourages confidence in these conclusions. Future work will need to ascertain how cognitive capabilities/deficits in ASD both relate to children’s behavioral symptoms, and contribute to the pathogenesis of autism.

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Table 1. Descriptive statistics for chronological age, verbal IQ, nonverbal IQ, and domain scores from the Autism Diagnostic Interview-Revised (ADI-R).

Variable		**Group**	
		ASD (N = 40)	**Typical development** (N = 40)
Age (in months)	M	67.15	65.70
	SD	10.92	11.47
	Range	49 – 88	48 – 88
Verbal IQ (PPVT standard score)	M	101.15	103.25
	SD	11.04	9.91
	Range	82 - 122	75 – 121
Nonverbal IQ (Leiter-R standard score)	M	113.58	112.52
	SD	14.11	14.47
	Range	83 - 141	91 – 143
Total ADI-R score (cutoff = 21)	M	40.40	
	SD	11.77	
	Range	9 – 63	
Social interaction (cutoff = 10)	M	17.05	
	SD	6.54	
	Range	1 – 28	
Communication (cutoff = 8)	M	13.12	
	SD	4.93	
	Range	1 – 22	
Repetitive behaviors (cutoff = 3)	M	6.60	
	SD	2.56	
	Range	2 – 12	

Table 2. Mean performance on central coherence, theory of mind, and executive functioning measures for ASD and comparison groups separately.

Measure		Group	
		ASD (N = 40)	**Typical development** (N = 40)
PEFT time	M	5.68	9.89
(in seconds)	SD	2.18	2.25
	Range	1.65 – 9.23	4.94 – 14.56
CEFT time	M	5.49	13.82
(in seconds)	SD	3.21	2.67
	Range	1.51 – 12.29	7.52 – 18.41
EFT time	M	5.59	11.85
(in seconds)	SD	2.50	2.32
	Range	1.84 – 10.71	7.00 – 15.83
Pattern Construction task	M	132.50	105.25
(ability score)	SD	17.25	13.75
	Range	108 – 182	75 – 141
Figure-Ground task	M	13.45	8.65
(total score out of 18)	SD	2.16	2.26
	Range	9 – 18	4 – 14
VMI task	M	11.25	13.00
(total score out of 24)	SD	2.80	2.90
	Range	6 – 18	7 – 22
ToM composite	M	4.18	8.02
(total score out of 14)	SD	3.64	3.96
	Range	0 – 13	0 – 14
Luria’s handgame	M	7.10	8.15
(Conflict condition; out of 10)	SD	1.64	1.46
	Range	4 – 10	5 – 10
Mazes task	M	14.35	15.38
(total score out of 26)	SD	4.63	3.00
	Range	4 – 22	10 – 25
Set-shifting task	M	45.05	38.22
(total score out of 60)	SD	9.79	7.92
	Range	27 – 58	24 – 53
Tower of London task	M	6.32	9.30
(total score out of 16)	SD	2.62	3.34
	Range	3 – 13	4 – 16

Table 3. Pearson correlation coefficients between variables in all three cognitive domains and chronological age, verbal ability, and nonverbal ability for ASD (N = 40) and typically developing (N = 40) groups separately.

Group	Measure	Age	Verbal ability	Nonverbal ability
ASD	EFT	-.28	-.27	-.35*
	Pattern Construction	.26	.42**	.44**
	Figure-Ground	-.02	.18	.34*
	VMI	.61**	.59**	.56**
	ToM composite	.23	.48**	.46**
	Luria's handgame	.41**	.46**	.58**
	Mazes	.52**	.57**	.56**
	Tower of London	.50**	.60**	.67**
	Set-shifting	-.38*	-.52**	-.47**
Typical development	EFT	-.60**	-.52**	-.41**
	Pattern Construction	.58**	.54**	.67**
	Figure-Ground	.23	.08	.34*
	VMI	.59**	.56**	.64**
	ToM composite	.64**	.54**	.54**
	Luria's handgame	.62**	.63**	.66**
	Mazes	.58**	.53**	.64**
	Tower of London	.48**	.65**	.57**
	Set-shifting	-.10	-.33*	-.06

** Significant at the 0.01 level (2-tailed)

* Significant at the 0.05 level (2-tailed)

Table 4. Pearson correlations and partial correlations between central coherence scores for ASD (N = 40) and typically developing (N = 40) groups separately.

Group	Correlation	Measures	EFT	Pattern Construction	Figure-Ground
ASD	Full	Pattern Construction	-.43**	-	
		Figure-Ground	-.33*	.34*	-
		VMI	-.30	.34**	.27
	Age partialled	Pattern Construction	-.39*	-	
		Figure-Ground	-.35*	.36*	-
		VMI	-.21	.24	.36*
	Age, verbal & nonverbal ability partialled	Pattern Construction	-.32*	-	
		Figure-Ground	-.28	.22	-
		VMI	-.16	.11	.28
Typical development	Full	Pattern Construction	-.48**	-	
		Figure-Ground	-.23	.05	-
		VMI	-.52**	.71**	.10
	Age partialled	Pattern Construction	-.21	-	
		Figure-Ground	-.11	-.10	-
		VMI	-.25	.56**	-.05
	Age, verbal & nonverbal ability partialled	Pattern Construction	-.26	-	
		Figure-Ground	-.19	-.23	-
		VMI	-.28	.47**	-.13

** Significant at the 0.01 level (2-tailed)

* Significant at the 0.05 level (2-tailed)

Table 5. Pearson correlations and partial correlations for relationships of central coherence variables with theory of mind variables and executive functioning variables for ASD (N = 40) and typically developing (N = 40) groups separately.

Group	Correlation	Measure	ToM	Luria's handgame	Mazes	Tower of London	Set-shifting
ASD	Full	EFT	-.15	-.29	-.24	-.34*	.23
		Pattern Constr.	.40*	.18	.43**	.57**	-.44**
		Figure-Ground	.38*	.27	.35*	.38*	-.30*
		VMI	.41**	.57**	.74**	.56**	-.65**
	Age partialled	EFT	-.09	-.20	-.12	-.24	.14
		Pattern Constr.	.36*	-.08	.36*	.53**	-.38*
		Figure-Ground	.40*	.30*	.42**	.45**	-.34*
		VMI	.35*	.44**	.61**	.37*	-.57**
	Age, & verbal ability partialled	EFT	-.04	-.17	-.08	-.20	.10
		Pattern Constr.	.25	-.01	.27	.36*	-.28
		Figure-Ground	.34*	.25	.37*	.39*	-.27
		VMI	.23	.38*	.56**	.26	-.50**
	Age, verbal, & nonverbal ability partialled	EFT	.01	-.11	-.04	-.14	.06
		Pattern Constr.	.20	-.12	.23	.29	-.25
		Figure-Ground	.28	.11	.32	.27	-.22
		VMI	.21	.36*	.55**	.24	-.49**
Typical development	Full	EFT	-.38*	-.51**	-.38*	-.23	.29
		Pattern Constr.	.47**	.63**	.70**	.50**	-.25
		Figure-Ground	.24	.09	.15*	.24	.02
		VMI	.56**	.62**	.61**	.50**	-.13
	Age partialled	EFT	.01	-.22	-.04	.09	.29
		Pattern Constr.	.16	.42*	.56**	.32*	-.23
		Figure-Ground	.12	-.07	.02	.14	.05
		VMI	.30*	.40*	.40**	.30	-.09
	Age, & verbal ability partialled	EFT	.04	-.17	-.01	.21	.24
		Pattern Constr.	.13	.38*	.54**	.24	-.17
		Figure-Ground	.14	-.03	.04	.24	.00
		VMI	.28	.34*	.37*	.21	.01
	Age, verbal & nonverbal ability partialled	EFT	.03	-.23	-.06	.18	.23
		Pattern Constr.	.12	.30	.47**	.16	-.25
		Figure-Ground	.13	-.13	-.07	.17	-.05
		VMI	.27	.28	.30	.14	-.04

** Significant at the 0.01 level (2-tailed)

* Significant at the 0.05 level (2-tailed)

Table 6. Summary of discriminant function analysis (N = 80).

	Stepwise analysis				Hierarchical analysis
Predictor	Rao's V [a]	Change in V	Standardized coefficients	Pooled within groups correlation with discriminant function	Rao's V test of increased ability to discriminate groups when added last to the function
Embedded Figures	135.16	135.16	.503	.566	χ^2 (5, N = 80) = 59.32, $p < .001$
VMI	206.03	70.86	.316	.134	χ^2 (6, N = 80) = 3.71, ns.
Figure-Ground	260.70	54.67	-.540	-.473	χ^2 (6, N = 80) = 100.84, $p < .001$
ToM	312.57	51.88	.408	.220	χ^2 (5, N = 80) = 42.46, $p < .001$
Pattern Construction	374.71	62.14	-.610	-.380	χ^2 (5, N = 80) = 78.02, $p < .001$
Tower of London	421.89	47.18	.448	.215	χ^2 (6, N = 80) = 33.70, $p < .001$

[a] At each step, the variable that produces the largest increase in Rao's V is entered.

Appendix A: Detailed procedure for Theory of Mind tasks

First-order false belief

Unexpected Transfer task. Six scenarios were presented via CD-ROM with child actors playing the characters. In three scenarios, children watched as one character displaced another character's object. They saw one character (e.g., Sarah) leave an object in one location and then leave the scene. While the character was away, another character (e.g., Andy) shifted the object to a different location. Children were then asked by the experimenter to predict where the first character would look for the object (e.g., "Where will Sarah look for her apple?"). Children were also asked a reality control question (e.g., "Where is the apple really?") and a memory control question (e.g., "Where was the apple in the beginning?"). In three additional scenarios, children watched as one character replaced another character's object with a different object. Children saw one character place an object in a particular location and then leave the room. While the character was absent, another character removed the object from the location, and replaced it with a different object. Control questions were also asked. For each of the six trials, children were asked to predict the returning character's false belief.

Unexpected Contents task. This task involved a prototypical box (Smarties box, milk carton, or egg carton), whose contents had been replaced with something unexpected (coloured pencils, rubber bands, or cotton wool). For example, the child was first shown a closed Smarties box and asked what he or she thought was inside. He/she was then told to open the box to see its actual contents (pencils). Children were then asked a test question requiring them to recall their own false belief, "Before you looked inside, what did you think was in the box?", and a reality control question, "What is in the box really?" After the own belief and control questions, a puppet, Elly, was taken out and placed in front of the box. The children were then asked a second test question to predict Elly's false belief, "What will Elly think is inside the box?", as well as a second control question, "What is in the box really?"

Second-Order ToM task

Children watched two CD-ROM scenarios involving an unexpected transfer. They observed a character (e.g., Jane) place an object (e.g., a book) in a location and then leave the room. Another character (e.g., Tom) transferred the object to a different location. However, unbeknownst to Tom, Jane was watching the transfer through a window. The child was then asked to predict where Tom would think that Jane would search for the object when she returns, (e.g., "Where will Tom think that Jane will look for her book?"). Reality control (e.g., "Where is the book really?") and memory control (e.g., "Where did Jane put the book in the beginning?") questions were also asked.

Footnotes

1. Whilst possible relationships between performance on measures of ToM and EF in autism are of theoretical interest, they are beyond the scope of this paper and are not discussed further.
2. As suggested by an anonymous reviewer, we also examined a more homogenous autism group by using more stringent inclusion criteria: children who had a clinical diagnosis of autism *and* who met criteria on all 3 ADI-R domains. This resulted in 23 out of 40 children who fell into a ‘pure’ autism group and 17 children who fell into a PDD-NOS group. ANOVAs were conducted to compare these two clinical groups on each cognitive variable. No significant group differences were found (all ps > .05). Given that we failed to find significant evidence of the diversity of the ASD sample affecting the central results, we decided to retain all 40 children in subsequent analyses.
3. The use of these four subtests from the Leiter-R as an estimate of nonverbal ability is not an established procedure. However, it was justified when a principal components analysis with varimax orthogonal rotation was conducted on the four subtest scores across both groups of children (N = 80). The analysis yielded a single factor that explained 55% of the variance in the data. We also conducted a further principal components analysis on the ASD group alone; again, a single factor emerged, which explained 60% of the variance in subtest scores.
4. Six trials from the PEFT used stimuli that were also present in the CEFT. Intercorrelations between latencies derived from trials unique to each test and latencies derived from trials involving repeated stimuli were moderate to high, the lowest being, r (80) = .64, p < .001. Therefore, the composite score (EFT time) reported reflects an average across all successful PEFT and EFT trials.

5. Note that only one component of ToM ability was tested here, that of false belief understanding. Therefore, intact performance on such tasks does not necessarily preclude the presence of other deficits in understanding other minds.
6. It is important to note that despite having potentially greater reliability than the ToM and EF tasks, the CC measures were not highly intercorrelated once individual and developmental differences were adjusted for. This causes us to feel quite confident that performance on the visuospatial coherence measures were not driven by an underlying mechanism of coherence.
7. It should also be noted that, unlike in the ADI-R, information regarding repetitive behaviors is not included in the formal diagnostic algorithm of the ADOS.