Are Abilities Abnormally Interdependent in Children with Autism?

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Abstract

We propose that stronger than usual correlations between abilities indicate which cognitive processes are impaired in autism. Study 1 compared partial correlations (controlling age) between intelligence and social cognition in children with autism (n = 18), mental retardation (n = 34), or no psychological disorder (n = 37). Correlations were stronger in the autism group. Study 2 compared correlations between measures of perceptual organization and verbal comprehension, receptive and expressive language, fine and gross motor coordination, and theory of mind, emotion recognition, and emotion understanding abilities in children with autism (n = 30) or mental retardation (n = 24) and in a large representative sample of children (n = 449). Results indicate that autism is marked by stronger correlations between all ability domains and mental retardation is marked by stronger correlations between motor coordination tasks and other ability measures.

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The developmental disorders included in the DSM-IV do not define discrete syndromes that are readily discriminable from other syndromes, but domains of underachievement and/or impairment relative to age norms or to an individual child's general level of intelligence. Underachievement in one domain is frequently associated with underachievement in other domains, which means that children often meet diagnostic criteria for two or more developmental disorders. This comorbidity is not surprising because ability domains are not independent of each other. In typically developing children, the likelihood that underachievement in one domain will be accompanied by underachievement in other domains varies predictably as a function of the correlation between abilities. When ability domains such as intelligence and language are strongly correlated, large discrepancies in achievement are unlikely and children selected on the basis of low scores on language tests will typically also achieve low scores on intelligence tests (Dyck, Hay, Anderson, Smith, Piek & Hallmayer, 2004b).

A pattern of comorbidity that is consistent with statistical expectation implies that the mechanisms responsible for a correlation between ability domains are unimpaired. Impairment is suggested when observed patterns of achievement are *inconsistent* with expectation, as when abilities that are normally independent of each other become highly interdependent. An example of increased interdependence between abilities is the strong association between motor deficits and other deficits in children with developmental disorders. In typical children, motor coordination is weakly related to intelligence (r = .21), language (r = .22), social cognition (r = .23), and executive functions (r = .22; Dyck et al., 2004b). On this basis, underachievement in other ability domains should not usually be accompanied by underachievement in motor skills. For example, Dyck et al. (2004b) observed that among children selected from a representative sample on the basis of low language scores, only 25% also obtained low motor coordination scores. By comparison, up to 69% of children with ADHD, 63% of children with dyslexia, and 90% of children with a specific language impairment also met diagnostic criteria for motor skills disorder (Hill, 2001; Kadesjo & Gillberg, 2001; Kaplan et al., 1998; Piek, Pitcher & Hay, 1999; Pitcher, Piek & Hay, 2003; Ramus et al., 2003).

Increased interdependence between abilities implies that some unusual constraint has been imposed on the ability domains. At least two kinds of constraint can be envisaged. The first is where an impairment has flow-on effects and is illustrated by children with hearing impairments. Deaf children not exposed to sign language from infancy are delayed in acquiring language (Courtin, 2000), which in turn affects achievement on tests that depend on language ability, including verbal but not performance intelligence tests (Isham & Kamin, 1993; Watson, Sullivan, Moeller & Jensen, 1982). The second constraint is the opposite kind, where an intact ability facilitates performance on tasks that typically depend on the impaired process. This is the kind of constraint that has been proposed to account for the fact that individuals with autism sometimes achieve better than expected results on tasks that ostensibly measure core deficits in autism (Volkmar, Lord, Bailey, Schultz & Klin, 2004). Functional MRI studies suggest that “even when people with autism produce normal behavioral output, they tend to do so by abnormal physiological means” (Belmonte & Yurgelun-Todd, 2003, p. 652), that is, they rely on different cognitive processes than do typically developing persons.

A simple way to gauge whether abilities are unusually constrained in a disorder is to assess whether correlations between abilities are greater among people with the disorder than among people with other or no disorders. A stronger correlation would not reveal whether the constraint was limiting or compensatory, only whether the relationship was constrained. The potential importance of this simple test is that it represents a way to map cognitive domains that are affected by a disorder and, when combined with other information, to suggest upon which cognitive resources persons with the disorder are forced to rely.

Belmonte and Yurgelun-Todd (2003, p. 652) suggest that in persons with autism, ‘higher’ processes compensate for impairments in more basic ones. For example, Toichi and Kamio (2001) observed that in an autism, but not in a control group, performance on a semantic priming task for related words was both poorer and significantly correlated with performance IQ and Ravens Colored Progressive Matrices (RCPM) scores. Toichi and Kamio (2002) observed comparable between-group differences in how material is processed into long-term memory; performance by the autism group on graphic, phonological and semantic processing tasks was poorer and more strongly correlated with verbal IQ, performance IQ and RCPM scores. If intelligence tests measure ‘higher’ cognitive processes, these processes are more strongly related to basic verbal association and level of processing tasks in autism than in control groups. We expect that such stronger relationships will also be observed when autism is compared with a different severe developmental disorder. We test this hypothesis, and the potential utility of using differences in the strength of correlations across samples to map constrained relationships in two studies.

In the first study, we assess whether correlations between measures of higher processes (intelligence tests) and measures of social cognition are stronger in children with Autistic Disorder (AD) than in children with Mental Retardation (MR) or typical children (TC). In the second study, we assess correlations within a much broader set of ability measures and include a large representative sample.

Study 1

In the first study we analyzed data from research that was designed to assess whether theory of mind and emotion recognition/understanding tasks discriminate between groups of children with different autism spectrum disorders and whether these tasks discriminate between groups of children with and without an autism spectrum disorder (Dyck, Ferguson, & Shochet, 2001). The original study showed that when IQ was controlled, the AD group had significantly lower emotion recognition / understanding ability than the MR group, which in turn had lower scores than the TC group. The study did not examine which mechanisms might be responsible for individual differences in performance on social cognition tasks. A possible interpretation of the presumed impairment of ‘theory of mind’ (Baron-Cohen & Swettenham, 1996) and ‘face recognition’ (Klin et al., 1999) mechanisms in persons with autism is that achievement on measures of these abilities depends primarily on general mechanisms, such as intelligence, rather than on the specific mechanism. This proposition is supported by functional MRI studies showing that adolescents with autism use atypical neurological processes when completing face recognition tasks (Pierce, Muller, Ambrose, Allen, & Courchesne, 2001; Schultz, Gauthier, Klin et al., 2000). As a result, we predicted that stronger correlations between measures of theory of mind and intelligence, or recognition of facial expressions of emotion and intelligence, would be evident among children diagnosed with autism than among children with MR or no disorder. MR is an appropriate comparison group because the severity of impairment is similar to that in AD, but the cognitive impairments are regarded as general rather than specific. This means that it is unlikely that children in this group would use compensatory processes to facilitate achievement on social cognition tasks.

Method

Participants and Procedure

After approval from Griffith University Human Research Ethics Committee, participants were recruited from hospitals, clinics, special education units, and schools in Brisbane, Australia, where they had been identified by institutional staff. Information on the diagnostic status of potential participants was obtained from the responsible clinician (hospitals/clinics) or from files (school system). For file information, we verified that diagnosis was by a specialist practitioner and that the diagnosis was corroborated by test results, as appropriate.

Of the original 20 participants with a DSM-IV diagnosis of Autistic Disorder, 2 were excluded because their above average IQs substantially increased the range of scores in the *AD group*. The AD group comprised 18 children (15 boys) with a mean age of 12.44 years (*sd* = 2.59) and a mean IQ of 62 (*sd* = 14.82; range 40 – 95). Eleven of these children also had a diagnosis of mental retardation. The *MR group* comprised 34 children (18 boys) whose DSM-IV diagnosis of mild mental retardation was not a function of Down Syndrome. The mean age of the MR group was 12.23 years (*sd* = 1.95), and the mean IQ was 56 (*sd* = 10.11; range 40 – 76). One child also had a diagnosis of Tourette's Disorder. The *TC group* consisted of 37 children (27 boys) with no parent or teacher report of a history of psychological disorder and who obtained parent-rated Child Behavior Checklist ratings in the normal range (T-score < 70) on all scales. The mean age of the TC group was 12.35 years (*sd* = 2.41) and the mean IQ was 101 (*sd* = 15.69; range 71 – 146).

Upon obtaining the written informed consent of a parent or guardian and the agreement of participants, participants were individually assessed where they were recruited. Test administration followed a standard order designed to maximize task-engagement. Testing typically required a single two-hour session.

Materials

The *Facial Cues Test* (FCT) measures the ability to recognize facial expressions of emotion, including expessions of anger, contempt, disgust, fear, happiness, sadness, surprise and neutral expressions (Matsumoto & Ekman, 1995). The FCT is internally consistent in these samples (α = .74; Dyck et al., 2001) and in samples of children with sensory disabilities (α = .92; Dyck et al., 2004a). It is moderately to strongly (*r* = .51 to .72) related to the other social cognition measures used here (Dyck et al., 2001).

The *Emotion Vocabulary Test* (EVT) measures the ability to define emotion words (what does the word “angry” mean?). The EVT is internally consistent in these samples (α = .88; Dyck et al., 2001) and in samples of children with sensory disabilities (α = .89; Dyck et al., 2004a), and has good inter-rater reliability (*r* = .94; Dyck et al., 2004a). The EVT is moderately to strongly (*r* = .65 to .72) related to the other social cognition measures used here (Dyck et al., 2001).

The *Comprehension Test* (CT) measures the ability to understand the emotional consequences of exposure to an emotion-eliciting context (Susan is given a new bicycle for her birthday. What will Susan feel?). The CT has acceptable internal consistency in these samples (α = .64; Dyck et al., 2001) and in samples of children with sensory disabilities (α = .79; Dyck et al., 2004a), and has good inter-rater reliability (*r* = .84; Dyck et al., 2004a). The CT is moderately to strongly (*r* = .51 to .65) related to the other social cognition measures used here (Dyck et al., 2001).

The *Unexpected Outcomes Test* (UOT) measures the ability to apply reasoning skills and knowledge of the causes of emotions to explaining apparent incongruities between an emotion-eliciting context and the emotion elicited by the context. UOT items provide information about a situation that is likely to cause an emotional response in a protagonist (John likes a girl called Susan, and he wants her to go to the movies with him. When he asks her, she says yes). Items then indicate what emotion has been experienced (On their way to the movies, he is very angry). In each case, the emotion differs from what is usually expected to occur in the situation. The test-taker must explain the apparent incongruity. The UOT is internally consistent in these samples ($\alpha = .78$) and in samples of children with sensory disabilities ($\alpha = .81$; Dyck et al., 2004a), and has good inter-rater reliability (r =.85; Dyck et al., 2004a). The UOT is moderately to strongly (r = .51 to .69) related to the other social cognition measures used here (Dyck et al., 2001).

The *Strange Stories Test* (SST) assesses the ability to provide context-appropriate mental state explanations for non-literal (irony, sarcasm, lies) statements (Happe, 1994b). The SST is internally consistent in these samples ($\alpha = .85$; Dyck et al., 2001), and it is moderately to strongly (r = .51 to .71) related to the other social cognition measures used here (Dyck et al., 2001).

Wechsler Intelligence Scale for Children-III. Cognitive ability was measured with four Wechsler Intelligence Scale for Children, 3rd edition (Wechsler, 1992) subscales—Vocabulary, Information, Block Design, and Picture Arrangement—selected because they sample verbal comprehension and perceptual organization, because of their strong relation to the full scale IQ (Sattler, 1988), and because they assess strengths and weaknesses associated with autism (Happe, 1994a).

Results

Prior to statistical analyses, we screened for skewness, kurtosis and outliers ($z > +/- 3.0$) in the distributions of each variable, and for bivariate outliers (examination of scatter plots) in each pair of distributions. Strange Stories Test scores were moderately negatively skewed in the TC group, Emotion Vocabulary Test and Unexpected Outcome Test scores were moderately positively skewed in the AD group, and Emotion Vocabulary Test scores were moderately positively skewed in the MR group (see Table 1). We reflected the negatively skewed scores before conducting square root transformations of all skewed distributions. Following transformation, skew and kurtosis statistics were satisfactory for the Strange Stories Test in the TC group (.85, .62), the Emotion Vocabulary Test in the AD (.08, -.66) and MR groups (.56, .08), and for the Unexpected Outcomes Test in the AD group (.60, -.71). No outliers were identified. Information on group achievement on each composite variable, before transformation, is reported in Table 1. Ranges are approximately equal in the AD and TC groups but are narrower in the MR group.

For each diagnostic group, we conducted partial correlation analyses based on test raw or transformed scores and controlling for age. Partial correlations obtained from TC and AD children are reported in Table 2, which shows that correlations are higher in the AD group. We used Fisher's r to z procedure to test the significance of these differences. In total, 12 of 36 correlations are significantly ($p < .05$, two-tailed) stronger in the AD group (2 correlations would be expected to differ 'significantly' by chance). Correlations that do not differ in the two groups involve Block Design (8 correlations), Picture Arrangement (8 correlations) and the Unexpected Outcomes Test (4 correlations).

Results obtained from the TC and MR groups are also reported in Table 2. Three correlations differ for the MR and TC groups: correlations between Wechsler

Information and the Strange Stories Test and between the Strange Stories and Unexpected Outcomes Tests are stronger in the MR group, while the correlation between Wechsler Information and the Comprehension Test is stronger in the TC group. This pattern of results is consistent with what might be expected by chance. When the MR and AD groups are compared, significantly stronger correlations in the AD group are evident in 11 of 36 cases. In 8 cases, these are the same correlations that differ between the AD and TC groups.

Discussion

The results provide evidence of stronger relationships between abilities in children with autism, but not in children with mental retardation. The contrast between the AD and MR groups is striking given that 11 of the children in the autism group had also been diagnosed with mental retardation. In the AD group, correlations between most variables are sufficiently strong that it must be questioned whether the tests are measuring distinct ability domains. One implication of this result is that performance on these tasks may depend on general intellectual processes rather than on specific theory of mind or face/emotion recognition mechanisms.

The overall pattern of results suggests that verbal comprehension is more strongly involved in compensation than is perceptual organization, as measured by Block Design. This variable (and Picture Arrangement) was less strongly related to other variables in persons with autism. This is an interesting result because the Block Design task is one on which AD groups frequently attain their highest scores (e.g., Dennis et al., 1999; Happe, 1994a) and, in general, it might be regarded as a marker of the higher intellectual processes available to assist achievement on other tasks. The fact that this was not the case may be due to the strong verbal component of the social cognition tasks. If true, we can expect that perceptual organization measures would be much more strongly related to tasks in which verbal demands are limited.

Study 2

The results of study one support the hypothesis that some abilities are unusually constrained in persons with autism, but whether this constraint is specific to verbal comprehension and social cognition measures is unknown. The idea that the magnitude of correlations can be used to map ability domains that have been brought into closer than usual alignment in autism presupposes the administration of a large set of tasks sampling a broad range of ability domains. The second study was designed to achieve this aim by sampling perceptual organization and verbal comprehension, receptive and expressive language, social cognitive abilities, and fine and gross motor coordination in AD, MR and TC groups.

Method

Participants and Procedure

Participants were recruited after the project had gained the approval of Curtin University Human Research Ethics Committee. The *AD group* comprised 30 children (23 boys) with a mean age of 8.47 years (*sd* = 2.63) who were recruited through a state autism register (Glasson, 2002) and research networks. Children who exceeded a cut-off score of 14 on the Social Communication Questionnaire (SCQ; Rutter, Bailey, Berument, Lord & Pickles, 2001) were assessed with the Autism Diagnostic Interview – Revised (ADI; Lord, Rutter & Le Couteur, 1999). Children were required to have shown abnormality in at least one domain prior to age 36 months (mean = 3.83; *sd* = 1.22), to obtain scores of 10 or higher on 'social' items (mean = 21.62; *sd* = 4.99), 8 or higher on 'communication' items (mean = 16; *sd* = 4.60), and 3 or higher on 'restrictive and repetitive behavior' items (mean = 6.52; *sd* = 2.69). Of 41 potential participants, 11 children were excluded, one because of an SCQ score < 14, two because they achieved criterion on only 3 of the 4 ADI scales, two because they were non-verbal, one for pragmatic reasons (excessive travel time), and five because symptomatic behavior (e.g., tantrums) precluded valid assessment.

Parents were asked to report on any other disorders that had been diagnosed in their child. In 14 cases, no other disorder was reported. In 15 cases, one to eight additional physical or mental disorders were reported. Comorbid mental disorders included ADHD = 9, MR = 2, mixed receptive-expressive language disorder = 1, dyspraxia = 2, learning disorder = 1, sleep disorder = 3, and depression = 1. Physical disorders included epilepsy = 1 and cerebral palsy = 1.

The *MR group* comprised 24 children (12 boys) with a mean age of 11.56 years (*sd* = 2.45) who were recruited through a health department database. Selection criteria included a diagnosis of mild mental retardation supported by the results of standardized measures of intelligence and adaptive functioning, no diagnosis of a genetic cause of the mental retardation (Heber classifications 69.00, 79.00, 89.00), and no diagnosis of an autism spectrum disorder. Parents were asked to report on any other disorders that had been diagnosed in their child. In 16 cases, no other disorder was reported. In 8 cases, one to three additional physical or mental disorders were reported. Mental disorders included ADHD = 6 and learning disorder = 2. Physical disorders included epilepsy = 1 and undiagnosed physical delays = 1.

The *representative sample* or *TC group* comprised 449 children (220 boys) with a mean age of 8.72 years (*sd* = 2.30) recruited from schools/preschools in Perth, Australia. Schools were targeted based on their position on an index of average student achievement, i.e., because they represented the distribution of academic achievement within Western Australia.

Upon obtaining the written informed consent of a parent or guardian, and the agreement of participants, participants in the AD and MR groups were individually assessed at their homes, schools, and/or at a university, depending on parental preference. Testing followed a prescribed order and was conducted in three sessions (2.5 hours, 2.5 hours, 1.25 hours) over two or three days. Participants in the TC group were assessed individually at their schools (n = 215) or as part of Project KIDS (n = 234), a large-scale, long running project in which data are collected for child-related research in school holiday periods. For children participating in Project KIDS, groups of up to 12 children were scheduled for a full day (8:45 a.m. to 4:30 p.m.) of activities, which included 3 90-minute assessment sessions. The order of test administration was uniform except for children in Project KIDS, where each child had his/her own schedule. If scheduled activities could not be completed, they were deferred to the end of the day where one hour of unallocated time was available to administer deferred tasks. Testing was usually completed within 4.5 hours, but sometimes required up to 5.5 hours. All tests were individually administered.

Measures

Intelligence was measured with four subscales from the third edition of the *Wechsler Intelligence Scale for Children* (WISC; Wechsler, 1992)—Vocabulary, Information, Block Design, and Picture Completion. The WISC subtests were selected because they represent the verbal comprehension and perceptual organization components of intelligence and because they provide a good estimate of fullscale IQ. Each test has excellent split-half and test-retest reliability, and both criterion and concurrent validity are well-established (Wechsler, 1992). Reliability of the tests in the current samples (AD/MR and TC, respectively) was α = .92 and .93 for

Information, α = .94 and .93 for Vocabulary, α = .90 and .96 for Block Design, and α = .89 and .92 for Picture Completion.

Language ability was estimated with four subscales from the third edition of the *Clinical Evaluation of Language Fundamentals* (CELF; Semel, Wiig, & Secord, 1995)—Concepts and Directions, Word Classes, Recalling Sentences, and Formulated Sentences. We selected the CELF partly because it has been standardized across a wide range of ages. Specific scales were selected because they are the only CELF scales which are administered to all children and because they sample receptive (Concepts and Directions, Word Classes) and expressive (Recalling Sentences, Formulating Sentences) language. These subscales have acceptable internal consistency (α = .54 to .91), test-retest reliability (.69 to .87), and concurrent validity [correlations with earlier versions of the test (r = .42 to .75) and with the Wechsler scales (r = .58 to .75) (Semel et al., 1995)]. Reliability of the tests in the current samples (AD/MR and TC, respectively) was α = .96 and .95 for Concepts and Directions, α = .93 and .95 for Word Classes, α = .95 and .96 for Recalling Sentences, and α = .96 and .96 for Formulating Sentences.

Motor coordination was assessed with the *McCarron Assessment of Neuromuscular Development* (MAND; McCarron, 1997). The MAND comprises 10 tasks, of which five assess fine motor skills (Beads in a Box, Beads on a Rod, Nuts and Bolts, Finger Tapping, Rod on Slide) and five assess gross motor skills (Finger /Nose/Finger, Hand Strength, Heel to Toe Walking, Jumping, One Foot). These tasks have acceptable test-retest reliability (.67 to .98), criterion validity (e.g., prediction of work performance), and concurrent validity [correlations with the O'Connor Finger Dexterity Test (r = -.41 to -.62), simple reaction time (r = -.31 to -.58), finger tapping (r = .35 to .53), and choice reaction time (r = -.45 to -.62) (McCarron, 1997)].

Reliability of the tests in the current samples (AD/MR and TC, respectively) was α = .92 and .92 for Beads in a Box, α = .86 and .89 for Beads on a Rod, α = .89 and .95 for Nuts and Bolts, α = .76 and .70 for Finger Tapping, α = .70 and .64 for Rod on Slide, α = .93 and .92 for Finger /Nose/Finger, α = .68 and .91 for Hand Strength, α = .94 and .84 for Heel to Toe Walking, α = .17 and .18 for Jumping, and α = .82 and .86 for One Foot.

Social Cognition. Social cognitive ability was estimated with a combination of three first-order and one second-order theory of mind tasks, an advanced theory of mind task (as in Study 1), and six subscales from the ERS (Dyck et al., 2001, 2004a). First order *theory of mind* tasks are false belief tasks commonly used to assess differences between children with/without some disorder, and included the “Sally Ann” (Baron-Cohen, Leslie & Frith, 1985), “Smarties” (Perner, Frith, Leslie & Leekam, 1989; Wimmer & Perner, 1983), and “Ella the Elephant” tasks (Harris, Johnson, Hutton, Andrews & Cooke, 1989). In each task, a child is asked whether a protagonist will act consistently with the protagonist’s beliefs, known to be false, or consistently with what the test-taker knows to be the true state of the world. Responses which indicate action consistent with the protagonist’s false beliefs are scored correct. The second-order theory of mind task, the “John and Mary icecream story” (Perner & Wimmer, 1985), is identical except that a child must assess what the protagonist thinks that another person thinks. We treated these tasks as separate items on a 4-point theory of mind scale. The reliability of this scale in the current samples is relatively poor (AD/MR, α = .51; TC, α = .64).

The Emotion Recognition Scales (ERS) include the three measures of emotion understanding ability used in Study 1 (Emotion Vocabulary Test, Comprehension Test, Unexpected Outcomes Test). The internal consistency of the three emotion understanding measures in the current samples (AD/MR and TC, respectively) was as follows: Emotion Vocabulary Test: α = .86 and 84; Comprehension Test: α = .78 and .79; Unexpected Outcomes Test: α = .64 and .77. The ERS also include two measures of emotion recognition ability—the Fluid Emotions and Vocal Cues tests—not used in Study 1.

The *Fluid Emotions Test* (FET; Dyck et al., 2004a) measures the ability to recognize static (as per the FCT in Study 1) and changed/changing facial expresions of emotion. This is a computer-presented test and items are drawn from Matsumoto and Ekman's (1995) color slides of adults expressing one of seven emotions (anger, contempt, disgust, fear, happiness, sadness, surprise) or a neutral expression. Each item consists of two head and shoulders pictures of a person expressing one of the 7 emotions or a neutral expression. The test-taker is asked what emotion is being expressed in the first picture. After responding, the image is transformed to another person expressing a different emotion. Subjects identify, as quickly as they can, the second emotion. Speed of response is measured with a stop-watch. Two FET scales were used: initial accuracy (ACC; initial emotions correct) and speed given accuracy (SGA). The SGA is based on the speed of accurate post-morph responses. Response latencies greater than 12 seconds are scored 0 whether the response is accurate or not. Latencies of 9 – 12 seconds are scored 1, and each subsequent 1 second decrease in latency results in an incremental score of 1. Latencies less than 4 seconds are scored 7. The internal consistency of the ACC and SGA were observed as α = .80 and .74, respectively, in children with developmental disorders, and as α = .90 and .94 in children with sensory disabilities (Dyck et al., 2004a). In the current samples, α = .88 (ACC) and α = .88 (SGA) in the combined samples of children with a diagnosis of AD or MR, and α = .65 (ACC) and α = .84 (SGA) in the TC sample.

The *Vocal Cues Test* (VCT; Dyck et al., 2004a) measures the ability to recognize vocal intonations specific to seven different emotions or an emotionally neutral expression. We used the VCT “Unreal” scale in which emotions are expressed using non-semantic content: numerals, letters, nonsense syllables. The VCT was shown to be internally consistent (α = .93) in a sample of vision-impaired and typical children (Dyck et al., 2004a). In the current samples, α = .91 in the combined samples of children with a diagnosis of AD or MR, and α = .85 in the sample of TC.

Data Transformations

In order to ensure that all ability measures had the same scale, we used data from the representative sample of children to create standard scores (mean = 100, *sd* = 15) for each variable. These standard scores were then used to create a set of composite scores, an unweighted average of standard scores on tests that have been defined *a priori* as part of the ability domain. The composite variables were as follows: *perceptual organization* (PO) was the average of Block Design and Picture Completion (r = .39, p < .01, in the TC group); *verbal comprehension* (VC) the average of Vocabulary and Information (r = .66, p < .01); *emotion recognition ability* (ER) was the average of Accuracy 1, Speed Given Accuracy, and Vocal Cues Test (r = .27 to .55, p < .01); *emotion understanding ability* (EU) was the average of Comprehension Test, Emotion Vocabulary Test, and Unexpected Outcomes Test (r = .22 to .35, p < .01); *theory of mind ability* (TM) was the average of the false belief tasks and Strange Stories Test (r = .13, p < .01); *receptive language ability* (LAR) was the average of Concepts and Directions and Word Classes (r = .51, p < .01); *expressive language ability* (LAE) the average of Formulating Sentences and Recalling Sentences (r = .52, p < .01); *fine motor coordination* (MCF) was the average of fine motor tasks (r = .11 to .49, p < .01) and *gross motor coordination*

(MCG) the average of the five gross motor tasks (r = .10 to .34, p < .01; for hand strength, finger nose finger, r = .01, *ns*).

Composite scores were restandardized by calculating age norms (mean and standard deviation in normative sample) for each composite measure so that each composite score had a mean of 100 and a standard deviation of 15. Although this procedure ensures that all composites have the same distribution in the population, when used with low scoring clinical samples it results in a larger range of scores than is obtained with conventional scoring. Tests like the Wechsler smooth and truncate distributions by converting raw scores to a limited set of age-referenced standard scores (e.g., mean = 10, range = 19, standard deviation = 3) prior to calculating composite scores. These conversions reduce score variability and force it to be equal across sub-tests. By retaining all variability, our procedure can yield extremely low scores, including negative IQ-equivalent scores (when the score is less than –6.66 standard deviations). To ensure that very low scores, and the associated increased range, cannot inflate observed correlations between measures, we set a minimum value of 20 for all composite scores. This restricts the range of scores in the autism and mental retardation groups, which decreases the chance of observing significantly stronger correlations in these groups than in the group of typical children.

Results

Prior to statistical analyses, we screened for skewness, kurtosis and outliers (z > +/- 3.0) in the distributions of each variable in the MR and AD groups, and for bivariate outliers (examination of scatter plots) in each pair of distributions. Receptive language composite scores were moderately positively skewed in the MR group (see Table 3). We conducted a square root transformation of receptive language scores in this group and, following transformation, skew and kurtosis statistics were satisfactory (.72, -.44). No outliers were identified. Information on group achievement on each of the composite variables is reported in Table 3. These results show that score ranges are approximately equal in the AD and TC Groups, but are consistently narrower in the MR group.

For each group, we conducted correlation analyses based on composite measures. Results are reported in Table 4, which indicates that correlations are higher in the AD than in the TC group. We used Fisher's r to z procedure to test the significance of these differences. In correlation matrices of this size and with alpha set at .05, two-tailed, two spuriously significant differences in either direction can be expected. We observed that 30 of 36 correlations are stronger in the AD group (see Table 4). Correlations that do not differ across groups involve emotion recognition (with perceptual organization, receptive language, fine motor coordination, and emotion understanding), and the relationships between perceptual organization and verbal comprehension and between gross motor coordination and emotion understanding.

Results obtained from the MR group (see Table 4) show that 9 correlations (2 expected by chance) were greater than those in the TC group. In 6 cases, the stronger relationships were between one or both measures of motor coordination and perceptual organization and verbal comprehension, emotion recognition and emotion understanding abilities. Emotion recognition ability was also more strongly related to expressive and receptive language abilities, and emotion understanding ability was more strongly related to verbal comprehension.

Comparison of the AD and MR groups (see Table 4) shows that 9 correlations (2 expected by chance) are stronger in the AD group. Perceptual organization is more strongly related to receptive language and theory of mind ability, verbal comprehension is more strongly related to receptive language, expressive language, and theory of mind ability, expressive and receptive language are both more strongly related to emotion understanding ability, and receptive language is more strongly related to fine and gross motor coordination. Thus, additional constraints affecting intelligence, language and social cognition distinguish the AD from the MR group.

Post hoc analyses

The very strong correlations between most ability measures in the AD group make it difficult to conclude that general intellectual processes are compensating for impairments in social cognitive abilities because measures of general intelligence share so much variance with all ability measures. In order to assess the specific contribution of general intelligence to performance on social cognition tasks, we used multiple regression analyses to assess the separate contributions of each ability variable in predicting theory of mind and emotion recognition composite scores in the three groups.

In the TC group, the 8 predictor variables accounted for an adjusted 23% of variance in theory of mind scores, but only one variable, expressive language, made a significant unique contribution to the regression (t = 3.68, p < .001; B = .235). In the MR group, the 8 predictor variables accounted for an adjusted 35% of variance in theory of mind scores, but only one variable, gross motor coordination, made a significant unique contribution to the regression (t = 2.15, p < .05; B = .675). In the AD group, the 8 predictor variables accounted for an adjusted 76% of variance in theory of mind scores, and both perceptual organization (t = 3.37, p < .01; B = .533) and fine motor coordination (t = -2.25, p < .05; B = -.471) made significant unique contributions to the regression. When emotion recognition ability was the dependent variable, 20% of adjusted variance was accounted for in the TC group, and three variables, perceptual organization (*t* = 2.27, *p* < .05; B = .123), emotion understanding (*t* = 4.32, *p* < .001; B = .226) and receptive language (*t* = 2.21, *p* < .05; B = .142) made significant unique contributions to the regression. In the MR and AD groups, the predictor variables accounted for 41% and 45% of adjusted variance in emotion recognition scores, respectively, but no predictor variable made a significant unique contribution to either regression.

Discussion

The results demonstrate that abilities are more strongly interdependent in the AD group than in the MR and TC groups. As in Study 1, correlations between variables in the AD group are so high that it must be questioned whether tests are measuring distinct ability domains in this group. Correlations between abilities like language and motor coordination, which are weak in the TC group, are as strong in the AD group (*r*s = .54 to .71) as are correlations among language and verbal comprehension measures in the TC group (*r*s = .58 to .67). Similarly, multiple regression analyses indicate that much larger proportions of variance in social cognitive abilities are accounted for by predictor variables in the AD group. These results suggest that some common factor among the predictor variables relates to social cognitive ability in this group (and, to a lesser extent, in the MR group). Granted that general intelligence or *g* is typically inferred from common variance in ability tests, this pattern of results may indicate that specific cognitive abilities have not been differentiated from general intelligence in persons with AD, and that general intelligence accounts for most variance across the set of ability domains. Alternatively, these results could indicate that the structure of ability in persons with AD must differ so markedly from the norm that the ‘intelligence’ of persons with AD is not comparable to the intelligence of other persons. If all cognitive processes are strongly interdependent in persons with AD, it may not be meaningful to distinguish general processes (intelligence) from specific ones.

General Discussion

We suggested that stronger than expected correlations between variables in persons with a disorder indicate that some abnormal constraint has affected relationships between ability domains. Our results suggest that in persons with AD, performance on intelligence tests is very strongly linked to performance on social cognition tasks. The results are consistent with a hypothesis that the primary impairment in AD is in the 'connectivity' of systems. Consistent with these findings, structural brain imaging has not implicated a specific brain region in AD. The most consistent finding—overgrowth in brain tissue volumes during the first years of life—has been interpreted as a marker of abnormal connectivity due to lack of pruning (Courchesne et al., 2003; Frith, 2003). Using diffusion tensor imaging, it could be shown that white matter structure is disrupted in subjects with AD (Barnea-Goraly et al., 2004), supporting the hypothesis that differences in the connections and trajectories of neural tracts rather than a localized lesion underlie the core symptoms of AD (Eigsti & Shapiro, 2003). Studying brain activation patterns during visuomotor learning, Muller et al. (2003) found significantly greater variability of activation foci in the AD group than in healthy controls. They propose that as a result of abnormal brain development in AD, less cortical processing territory is available for complex multimodal processing. Sensorimotor functions, which develop earlier in life, require larger areas of the brain to be activated. Implicit in their model is the notion that elementary functions interfere with more complex ones.

The idea that relationships between all ability domains are unusually constrained in AD challenges a basic assumption that is frequently made about the disorder; namely, that “the pathophysiology must involve only selected systems, sparing others, because autism is not incompatible with normative intelligence and domains of superior functioning” (Volkmar et al., p. 145). From our perspective, how *relationships* between intelligence and other domains have been affected by a disorder is more important than absolute level of ability within a domain. We would expect that the same abnormal constraints are evident in all persons with AD whether their achievement on intelligence tests is well below average, somewhat below average (as in our sample), or average. Consistent with this contention, Liss et al. (2001) reported correlations between Stanford-Binet verbal and quantitative IQs that are of similar magnitude in high functioning and low functioning children with AD, and which appear to be higher than those of children with other developmental disorders.

At all ability levels, whatever a child with AD attains on a task will be the result of non-normal information processing. We think that the exceptions to this rule will be restricted to relatively circumscribed tasks in which efficient connections across systems (e.g., language, executive functions, face processing) are not required (Plaisted, O’Riordan & Baron-Cohen, 1998; Rinehart et al., 2000; Ropar & Mitchell, 2002). On these tasks, children with AD will show superiority relative to their general ability baseline, and may show superiority relative to typical children. This means that the interesting question is not whether higher-order processes compensate for impairments in lower-order processes, but how impairments in the connectivity of cognitive systems change performance on most tasks in all ability domains.

Our methods are based on the assumption that abnormalities in neurocognitive processes which are shared by members of a diagnostic group affect the magnitude of correlations between ability domains in members of that group. However, the size of a correlation is also a function of the distribution of scores which may vary systematically across groups. Although we have attempted to minimize effects that might be attributable to between-group differences in the range of scores or the shape of distributions, the variance of scores and other parameters differed across groups and these differences may have reduced the reliability of our estimates of the difference between correlations. In Study 2, our samples also differed in age and sex ratios, and we cannot exclude the possibility that these differences influenced our results.

We argue that our results are consistent with the hypothesis that the primary impairment in AD is in the connectivity of systems. However, our findings need to be replicated using other methods. For example, our results indicate that in persons with AD, but not in persons with MR, performance on receptive language tasks is strongly associated with performance on gross motor coordination tasks. On this basis, in functional MRI studies, we might expect to observe increased cerebellar activation in response to receptive language tasks in persons with AD but not in persons with MR (cf. Allen & Courchesne, 2003; Manes et al., 1999).

Our results reveal abnormal interdependencies between all ability domains in children with AD. The observation of deviant relationships complements, and partly explains, the large body of research indicating that children with AD frequently have significant achievement deficits in these same domains. But even though our results may underscore the importance of assessing each child’s capacities across a broad range of abilities, they suggest that it is more important to assess how strengths or weaknesses in one domain may be affecting performance in other domains than to assess where a child’s greatest strengths/weaknesses may lie. The key assessment challenge would be to identify which set of weaknesses was contributing to a delay in a child’s achieving an important developmental milestone. For example, it would be important to consider to what extent a delay in acquiring language and/or a delay in acquiring representational abilities (including perspective-taking) might be contributing to a delay in acquiring a theory of mind. Ongoing assessment of which deficits are impeding the accomplishments of crucial developmental tasks would inform the changing priorities of treatment. Deciding how to enhance a child's social reciprocity and communication skills depends on whether a child needs to learn how to decode and label emotions (and learn what the appropriate labels are), how to use situational cues to make inferences about another person's emotions, or how to understand the relationships between emotions, desires, intentions, and other mental states (Eisenberg, Murphy, & Shepard, 1996).

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Table 1

Distribution of scores: Study 1

			AD Group						MR Group						TC Group		
	Mean	Range	SD	Skew	Kurt		Mean	Range	SD	Skew	Kurt		Mean	Range	SD	Skew	Kurt
CT	7.50	0 – 13 (13)	3.48	-.34	-.10		9.17	4 – 14 (10)	2.00	-.01	.82		12.51	9 – 18 (9)	2.31	.49	-.12
EVT	6.11	0 – 21 (21)	6.18	1.19	.30		6.88	1 – 21 (20)	4.71	1.31	1.60		24.18	13 – 39 (26)	6.82	.07	-.47
FCT	10.83	0 – 19 (19)	4.52	-.44	1.08		13.08	4 – 21 (17)	4.12	-.09	-.76		20.35	14 – 29 (15)	3.11	.40	.52
UOT	1.44	0 – 8 (8)	2.06	2.07	5.32		2.70	0 – 8 (8)	1.81	.59	.92		8.10	0 – 16 (16)	3.83	-.05	-.62
SST	3.11	0 – 10 (10)	3.39	.80	-.70		6.26	1 – 10 (10)	2.46	-.50	-.78		10.35	5 – 12 (7)	1.67	-1.57	2.69
BD	26.27	0 – 56 (56)	16.21	-.22	-.75		19.11	6 – 41 (35)	9.20	.29	-.31		43.64	13 – 68 (55)	13.04	-.25	-.32
INF	9.50	1 – 21 (21)	6.02	.65	-.33		9.23	4 – 16 (12)	2.80	.36	.04		18.35	11 – 25 (14)	3.73	.00	-.43
PA	16.00	0 – 38 (38)	11.39	.30	-.55		17.05	1 – 40 (39)	10.85	.47	-.61		36.94	16 – 61 (45)	11.56	.02	-.84
VOC	12.94	0 – 32 (32)	9.70	.57	-.70		15.58	8 – 26 (18)	4.37	.43	-.15		31.86	19 – 48 (29)	7.29	-.07	-.55

Abbreviations: CT = Comprehension Test; EVT = Emotion Vocabulary Test; FCT = Facial Cues Test; UOT = Unexpected Outcomes Test; SST = Strange Stories Test; BD = Block Design; INF = Information; PA = Picture Arrangement; VOC = Wechsler Vocabulary; SST = Strange Stories Test

Table 2

Partial correlations, controlling for age, among cognitive abilities

		FCT	EVT	UOT	SST	BD	INF	PA	VOC
TC Group	CT	.32	.22^{a}	.24	.24^{a}	.13	.43^{b*}	.44*	.25^{a}
	FCT		.32^{a}	.29	.28^{a}	.15	.17	.39*	.37*
	EVT			.18	.39^{a*}	.24	.19^{a}	.51*	.62*
	UOT				-.17^{ab}	.04	.18^{a}	.39*	.06^{a}
	SST					.36*	.24^{ab}	.16	.46^{a*}
	BD						.47*	.38*	.12
	INF							.43*	.60*
	PA								.31
AD Group	CT	.71^{c*}	.75^{ac*}	.52^{c*}	.71^{ac*}	.01	.65^{c*}	.39	.78^{ac*}
	FCT		.75^{ac*}	.46	.74^{ac*}	.26	.61*	.54*	.57*
	EVT			.59*	.85^{a*}	.08	.75^{a*}	.53*	.81*
	UOT				.63^{a*}	.02	.73^{ac*}	.52*	.79^{ac*}
	SST					-.05	.70^{a*}	.54*	.85^{ac*}
	BD						.33	.48	-.05
	INF							.61*	.84*
	PA								.53*

		FCT	EVT	UOT	SST	BD	INF	PA	VOC
MR Group	CT	.05[c]	-.02[c]	-.05[c]	.25[c]	.04	-.04[bc]	.11	-.12[c]
	FCT		.34[c*]	.04	.14[c]	.17	.24	.18	.23
	EVT			.34*	.58*	.30	.52*	.37*	.49*
	UOT				.40[b*]	-.07	.21[c]	.13	.23[c]
	SST					.31	.63[b*]	.45*	.40[c*]
	BD						.27	.63*	.22
	INF							.16	.56*
	PA								.17

Abbreviations: MR = Mental Retardation; AD = Autistic Disorder; TC = Typical Children; CT = Comprehension Test; EVT = Emotion Vocabulary Test; FCT = Facial Cues Test; UOT = Unexpected Outcomes Test; SST = Strange Stories Test; BD = Block Design; INF = Information; PA = Picture Arrangement; VOC = Wechsler Vocabulary; SST = Strange Stories Test

* the magnitude of this correlation differs significantly from 0 at the .05 level, two-tailed;

[a] the magnitude of this correlation in the AD group differs significantly from the corresponding coefficent in the TC group at .05, two-tailed;

[b] the magnitude of this correlation in the MR group differs significantly from the corresponding coefficent in the TC group at .05, two-tailed;

[c] the magnitude of this correlation in the AD group differs significantly from the corresponding coefficent in the MR group at .05, two-tailed.

Table 3

Distribution of scores: Study 2

			AD Group						MR Group						TC Group		
	Mean	Range	SD	Skew	Kurt		Mean	Range	SD	Skew	Kurt		Mean	Range	SD	Skew	Kurt
PO	75.14	20 – 130 (110)	31.67	-.17	-.70		41.96	20 – 73 (53)	18.22	.23	-1.09		100.00	50 – 138 (88)	15.01	-.28	-.04
VC	75.49	20 – 131 (111)	26.83	.03	-.04		42.03	20 – 67 (47)	16.45	.04	-1.25		99.99	49 – 147 (98)	15.01	-.16	1.09
EL	75.00	20 – 122 (102)	29.15	-.27	-.79		43.49	20 – 78 (58)	20.24	.15	-1.40		100.00	28 – 148 (120)	15.01	-.54	1.56
RL	69.31	20 – 124 (104)	32.02	-.22	-1.26		41.44	20 – 93 (73)	22.78	1.09	.40		99.98	46 – 147 (101)	15.01	-.39	.63
FMC	59.48	20 – 108 (88)	31.27	-.04	-1.50		43.12	20 – 84 (64)	24.50	.47	-1.46		100.38	36 – 132 (96)	15.00	-.82	1.45
GMC	51.45	20 – 97 (77)	23.94	.06	-1.07		37.84	20 – 82 (62)	19.50	.77	-.35		99.98	47 – 138 (91)	15.02	-.36	.31
ER	75.89	20 – 121 (101)	25.38	-.81	.16		62.74	20 – 100 (80)	19.75	-.35	.06		100.18	48 – 145 (97)	15.00	-.14	.24
EU	74.26	21 – 104 (83)	20.58	-.47	-.02		54.94	22 – 88 (66)	15.62	.09	-.06		99.95	50 – 142 (92)	15.01	-.18	.29
TM	65.64	20 – 125 (105)	29.77	.05	-1.01		51.38	20 – 115 (95)	25.82	.94	.22		99.98	20 – 137 (117)	14.96	-.64	1.51

Abbreviations: AD = Autistic Disorder; MR = Mental Retardation; TC = Typical Children; PO = Perceptual Organization; VC = Verbal Comprehension; EL = Expressive Language; RL = Receptive Language; FMC = Fine Motor Coordination; GMC = Gross Motor Coordination; ER = Emotion Recognition; EU = Emotion Understanding; TM = Theory of Mind

Table 4

Correlations among abilities

		VC	EL	RL	FMC	GMC	ER	EU	TM
TC Group	PO	.53*	.40^{a*}	.47^{a*}	.25^{ab*}	.18^{a*}	.30*	.24^{a*}	.27^{a*}
	VC		.62^{a*}	.58^{a*}	.13^{ab*}	.19^{ab*}	.30^{a*}	.47^{ab*}	.37^{a*}
	EL			.67^{a*}	.09^{a*}	.18^{a*}	.26^{ab*}	.46^{a*}	.42^{a*}
	RL				.23^{a*}	.23^{a*}	.34^{b*}	.43^{a*}	.39^{a*}
	FMC					.55^{ab*}	.21^{b*}	.06^{ab}	.13^{a*}
	GMC						.23^{a*}	.20^{b*}	.16^{a*}
	ER							.35*	.22^{a*}
	EU								.33^{a*}
AD Group	PO	.73*	.68^{a*}	.72^{ac*}	.68^{a*}	.65^{a*}	.49*	.64^{a*}	.75^{ac*}
	VC		.96^{ac*}	.84^{ac*}	.61^{a*}	.56^{a*}	.65^{a*}	.81^{a*}	.77^{ac*}
	EL			.85^{a*}	.62^{a*}	.54^{a*}	.67^{a*}	.85^{ac*}	.79^{a*}
	RL				.71^{ac*}	.68^{ac*}	.63*	.75^{ac*}	.78^{a*}
	FMC					.81^{a*}	.50*	.55^{a*}	.48^{a*}
	GMC						.60^{a*}	.47*	.56^{a*}
	ER							.57*	.69^{a*}
	EU								.69^{a*}

MR Group	PO	.51[*]	.30	.17[c]	.67[b*]	.54[*]	.35	.46[*]	.15[c]
	VC		.56[c*]	.34[c]	.74[b*]	.72[b*]	.52[*]	.85[b*]	.36[c]
	EL			.82[*]	.43[*]	.40	.70[b*]	.54[c*]	.66[*]
	RL				.23[c]	.21[c]	.71[b*]	.25[c]	.60[*]
	FMC					.81[b*]	.44[*]	.69[b*]	.28
	GMC						.36	.69[b*]	.46[*]
	ER							.48[*]	.46[*]
	EU								.37

Abbreviations: AD = Autistic Disorder; MR = Mental Retardation; TC = Typical Children; PO = Perceptual Organization; VC = Verbal Comprehension; EL = Expressive Language; RL = Receptive Language; FMC = Fine Motor Coordination; GMC = Gross Motor Coordination; ER = Emotion Recognition; EU = Emotion Understanding; TM = Theory of Mind

[*] the magnitude of this correlation differs significantly from zero at the .05 level, two-tailed;

[a] the magnitude of this correlation in the AD group differs significantly from the corresponding coefficent in the TC group at .05, two-tailed;

[b] the magnitude of this correlation in the MR group differs significantly from the corresponding coefficent in the TC group at .05, two-tailed;

[c] the magnitude of this correlation in the AD group differs significantly from the corresponding coefficent in the MR group at .05, two-tailed.