Exploring 'The Autisms' at a Cognitive Level

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Cathriona Cantio, Cand.psych. (1, 2), Jens Richardt Møllegaard Jepsen, MSc., PhD (3, 4), Gitte Falcher Madsen, MD, PhD (1), Niels Bilenberg, Professor, MD, PhD (1, 2), and Sarah White, PhD (5)

(1) Child and Adolescent Psychiatric Department, Odense, Mental Health Services, Southern Denmark

(2) Institute of Clinical Research, University of Southern Denmark

(3) Centre for Neuropsychiatric Schizophrenia Research & Centre for Clinical Intervention and Neuropsychiatric Schizophrenia Research, Copenhagen University Hospital, Psychiatric Hospital Centre Glostrup, Denmark

(4) Child and Adolescent Mental Health Centre, Mental Health Services Capital Region of Denmark, University of Copenhagen, Copenhagen, Denmark

(5) Institute of Cognitive Neuroscience, University College London, London, UK

Corresponding authors contact information

Cathriona Cantio, Child and Adolescent Psychiatric Department, Odense, Sdr. Boulevard 29, 5000 Odense C, Denmark, Tel.: +45 24658731, Email: cathriona.cantio@rsyd.dk

Lay abstract (229/250 words)

The autism spectrum is full of variation both in terms of the range of symptoms and differences between individuals. Even so, it is possible that a single cause might be present underneath this diversity in all individuals with autism. This study focussed on three well-known cognitive differences that are thought to affect the way people with autism process information: Theory of Mind (ToM), Executive Function (EF) and a Local Processing Bias (LB). 31 high-functioning children with ASD and 37 neurotypically-developing children of similar age, gender and intelligence completed several tasks within each cognitive domain. Everyday behaviours were also assessed through parent and teacher questionnaires, parent interview and direct observation. We found that ToM and EF difficulties were common and performance on these tasks could be used to accurately divide most of the children into those with and without ASD. Performance on these tasks was related to each other but not to any of the everyday behaviours. Only a small group of individuals with ASD had an LB, which didn't relate to the other measures; an LB may be the cause of symptoms that weren't included in an ASD diagnosis. Future studies may reinforce the idea that there is a single cause of autism in all affected individuals.

Scientific abstract

The autism spectrum is characterised by genetic and behavioural heterogeneity. However, it is still unknown whether there is a universal pattern of cognitive impairment in autism spectrum disorder (ASD) and whether multiple cognitive impairments are needed to explain the full range of behavioural symptoms. This study aimed to determine whether three widely acknowledged cognitive abnormalities (Theory of Mind (ToM) impairment, Executive Function (EF) impairment and the presence of a Local Processing Bias (LB)) are universal and fractionable in autism, and whether the relationship between cognition and behaviour is dependent on the method of behavioural assessment. 31 high-functioning children with ASD and 37 neurotypically-developing (NTD) children, comparable in age, gender and IQ, completed several tasks within each cognitive domain, and autistic symptomatology was assessed through parental and teacher questionnaires, parental interview and direct observation. We found that ToM and EF deficits differentiated the groups, were related to each other and were together able to correctly classify more than three-quarters of the children into cases and controls, despite relating to none of the specific behavioural measures. Only a small subgroup of individuals displayed an LB, which was unrelated to ToM and EF, and did not aid diagnostic classification, most likely contributing to non-diagnostic symptoms in a subgroup. Despite the characteristic heterogeneity of the autism spectrum, it remains a possibility therefore that a single cognitive cause may underlie the range of diagnostic symptoms in all individuals with autism.

Keywords: Autism Spectrum Disorders, Cognition, Theory of Mind, Executive Function, Local Bias, Fractionation, Symptomatology, and Behaviour

Exploring 'The Autisms' at a Cognitive Level

Autism spectrum disorder (ASD) is now widely accepted to be a neurodevelopmental disorder with a genetic basis resulting in atypical development of the brain, although relatively little is known about the exact genetic or biological abnormalities underlying the disorder (Betancur, 2011; Gliga, Jones, Bedford, Charman, & Johnson, 2014; Goldani, Downs, Widjaja, Lawton, & Hendren, 2014; Happe & Ronald, 2008; Lai, Lombardo, & Baron-Cohen, 2013). An ASD-diagnosis therefore relies upon a defined set of behavioural criteria, encompassing social interaction and communication difficulties and the presence of repetitive behaviours (*DSM-5*, American Psychiatric Association, 2013). A behavioural diagnosis has the disadvantage of heterogeneity: there can be many different causes of the same behaviour, or equally, different behaviours in different individuals can result from the same underlying cause due to interaction with other factors (Rutter, 2000). Indeed, the shopping list-style diagnostic criteria (Morton, 2008) now expect and furthermore embrace behavioural heterogeneity, leading the term 'the autisms' (Geschwind & Levitt, 2007) to enter the literature.

While it is acknowledged that different individuals vary wildly in their personal presentation of this shared diagnostic label (Geschwind, 2009; Munson, Faja, Meltzoff, Abbott, & Dawson, 2008; Ronald, Happe, Price, Baron-Cohen, & Plomin, 2006), this same heterogeneity is much harder to reconcile at a causal level of explanation. Still, heterogeneity is clearly evident at the genetic level: a host of rare genetic mutations have been identified but are thought to account for only 10-20% of autism cases (Abrahams & Geschwind, 2008), whilst genetic modelling indicates that autism is likely to result from 400-1000 risk genes interacting in complex ways (O'Roak et al., 2012). This has led the field to pursue endophenotypic markers that can homogeneously draw subgroups of individuals together (Charman et al., 2007) and heterogeneity certainly appears to decrease as we travel down the

causal chain from genetics to cognition. There is convergence from genetics to neurobiology, with evidence focussing around synaptic function (Zoghbi, 2003) and neural connectivity (Geschwind & Levitt, 2007); further convergence from cellular to systems neuroscience is apparent, with most emphasis placed on the frontal lobes, amygdala and cerebellum (Amaral, Schumann, & Nordahl, 2008). Whilst theories abound at the cognitive level, Theory of Mind (ToM), executive function (EF) and a local processing bias (LB) remain the most prominent (Brunsdon & Happe, 2014; Frith, 2012; Rajendran & Mitchell, 2007) drawing together diverse biological and behavioural findings.

It has thus been suggested that there may not be a unitary underlying cause of autism at any level and that leaving the "single explanation" approach behind may indeed be the key to identifying the genetic and neurocognitive origins of autism (Happe, Ronald, & Plomin, 2006); instead, it seems likely that a number of different mechanisms are required to explain different aspects of autistic symptomatology (Happe & Ronald, 2008). While such fractionation is evident at the behavioural level, it is still unclear whether the different proposed cognitive impairments in autism are similarly separable (Brunsdon & Happe, 2014); very few studies have examined ToM, EF and LB simultaneously in ASD and these findings have been contradictory (Brunsdon et al., 2014; Lai et al., 2012; Lam, 2013; Pellicano, Maybery, Durkin, & Maley, 2006). Furthermore, only one of these studies (Pellicano et al., 2006) has examined the relationship between cognition and symptomatology, finding no associations, and hence it is unknown whether these cognitive impairments really can explain independent aspects of autistic behaviour. One as yet unexplored possibility is that the detection of such relationships may be dependent on the tool used to evaluate diagnostic symptoms, whether assessed through parent or teacher report, through interview or direct observation. The present study therefore aims to provide further evidence to inform the fractionation debate at the cognitive and behavioural levels.

The idea of fractionating autism addresses the observation that there is no mechanism at any level of causality that is sufficient to explain the totality of the autistic syndrome. Inter-individual heterogeneity addresses a subtly different issue: whether there is any causal mechanism common to all individuals, a notion that is also widely presumed to be true but which has received much less empirical attention (Brunsdon & Happe, 2014). In fact, inter-individual heterogeneity has even been suggested to be a more distinct marker for autism than any one neuropathology (Towgood, Meuwese, Gilbert, Turner, & Burgess, 2009), attempting to explain why one study may find support for and the next find no evidence in favour of a particular underlying deficit. It remains an open question whether there is a universal pattern of impairment that can draw together all individuals with autism, or whether there is truth in the term 'the autisms' not just at a behavioural level but also at a causal level of explanation. The present study aims to address this issue.

This study therefore attempts to shed light on the following:

1) Are the cognitive impairments ToM, EF and LB fractionable in ASD?

2) Are any of these cognitive impairments common to all individuals with ASD?

3) Do these cognitive impairments predict autistic symptomatology?

4) Is the relationship between cognition and behaviour dependent on the method of behavioural assessment?

Method

We examined all three cognitive domains (ToM, EF and LB) in a large group of high-functioning children with ASD as well as a group of neurotypically-developing (NTD) children, comparable in age, gender and IQ. We used several tasks within each domain to ensure the validity of the cognitive measures and, given the propensity in the literature for high-functioning individuals with ASD to pass such tests, we selected tasks that have

previously been found to be sensitive. In addition, the children were comprehensively assessed with widely used instruments of autistic symptomatology, including parental and teacher questionnaires, parental interview and direct observation.

The study was approved by the Ethical Committee of the Region of Southern Denmark (S-20090071).

Participants

The ASD group was recruited from two Child and Adolescent Mental Health Services in the Region of Southern Denmark by searching the Patient Administrative System for date of birth (8-12 year olds) and ICD-10 diagnosis of Pervasive Developmental Disorder (F84.0-84.9). The diagnostic files were reviewed and children who did not fulfil an ASD-diagnosis or had a full-scale IQ (FSIQ) below 70 were excluded. A total of 82 clinically diagnosed children with ASD were invited to participate in the study, of which 54 families responded, from which 37 children agreed to participate. Three additional cases were recruited from special education schools for children with ASD.

Participants in the ASD group were only included if they also met DSM-IV-TR criteria for an ASD at the time of the assessment. An individual clinical conference of trained clinicians included all previous diagnostic information in conjunction with current scores on the ADOS and ADI-R (see below), and formed the basis for the confirmation of diagnosis. At this stage, 11 children met the criteria for Autistic Disorder, 7 for Asperger's Syndrome and 17 for Pervasive Developmental Disorder – Not Otherwise Specified (PDD-NOS). The remaining 5 children no longer fulfilled diagnostic criteria for an ASD and were excluded. Four further children were excluded due to current FSIQ below 70 leaving a total of 31 for analyses. FSIQ was estimated on the basis of three verbal and three performance subtests from the Danish translation of the Wechsler Intelligence Scale for Children (WISC-III, Wechsler, 2003).

The NTD children (N=37) were recruited from four different mainstream schools using similar inclusion criteria (FSIQ>70, age: 8-12 years). None of the NTD participants had elevated scores on the SRS or SCQ questionnaires (see below) or were otherwise reported or known to have any developmental disorder or family history of such difficulties.

The groups did not significantly differ on gender ($X^2(1)=0.97$), age ($t(63)=0.32$), performance IQ ($t(66)=0.60$) or verbal IQ ($t(64)=1.48$). The majority of children were Caucasian and from middle-class families, and we found no significant difference in their parents' educational level ($X^2(1)=.29$), defined by the highest ranking parent's education (more/less than 13 years of education; see table 1).

Behavioural assessment of symptoms

For the ASD group, autistic symptomatology was measured using the Autism Diagnostic Observation Schedule-Generic (ADOS, Lord et al., 2000) and Autism Diagnostic Interview, Revised (ADI-R, Lord, Rutter, & Le Couteur, 1994) in order to observe the child's behaviour in a clinical setting and to assess parents' perception of their children's disabilities (see table 1). All children reached the cut-off in ADOS social interaction, but seven children fell below cut-off in communication, and six children did not reach the total cut-off for communication and social interaction.

Symptomatology scores were recorded for both groups from parents and teachers using two different questionnaires: the Social Responsiveness Scale (SRS, Constantino et al., 2003) and the Social Communication Questionnaire (SCQ, formerly the Autism Screening Questionaire, Berument, Rutter, Lord, Pickles, & Bailey, 1999). Significant group differences were found on both questionnaires for parents (SRS, $t(35)=11.734$, $p<0.001$; SCQ, $t(36)=9.926$, $p<0.001$) and teachers (SRS, $t(42)=9.570$, $p<0.001$; SCQ, $t(43)=4.710$, $p<0.001$). Interestingly, parents in the ASD group tended to rate their children as having significantly more symptoms than the teachers did (SRS, $t(27)=2.671$, $p=0.013$; SCQ,

$t(26)=2.076$, $p=0.048$), whereas the opposite was true for the NTD group on the SCQ ($t(22)=3.976$, $p=0.001$; no difference on SRS, $t(25)=0.609$).

Table 1 about here

Instruments

ToM tasks. To assess advanced ToM abilities, we used White et al.'s (2009) modified Strange Stories for children, including the 5 sets of 8 stories: mental state, human, animal, nature and unlinked. We randomized both the order of story sets and the order of the stories within each set. Each story was read aloud by the experimenter, who then scribed the child's answers; these were later scored according to the criteria in White et al. (2009).

The Frith-Happé Animations were also employed; as in Salter, Seigal, Claxton, Lawrence, and Skuse (2008), we included four ToM and four Goal-Directed (GD) animations. These were administered in the same order for every child with two practice trials from the control random animations, followed by the GD and ToM animations presented alternately. Children's verbal responses to each animation were recorded and were later scored for intentionality and appropriateness according to Castelli et al. (2002).

EF tasks. We included tests of generativity (Verbal Fluency; Pattern Meanings), as well as the Cambridge Neuropsychological Test Automated Battery (CANTAB, Cambridge Cognition, 1996) which taps into planning (Stockings of Cambridge, SOC), working memory (Spatial Span, SSP; Spatial Working Memory, SWM) and flexibility (Intra-Extra Dimensional Set Shift, IED).

Generativity. Two Verbal Fluency tasks were used: letter and category fluency (Benton, 1968). We asked participants to generate as many different words as possible in 60 seconds. In the letter condition, all words were required to start with an F, excluding proper nouns. In the category condition, children were required to state as many animal names as possible. We recorded the number of correct answers after removing doublets and incorrect answers.

For the Pattern Meanings task, we used six meaningless line drawings taken from (Wallach, 1965); the first picture was a practice item, where alternative suggestions were made by the investigator as an illustration. Children were allowed to return to previously viewed items and were encouraged to give as many responses as possible within the 90 second time limit. Answers were scored for correct, repetitive, redundant, not useful, incorrect and unscorable answers, according to Bishop and Norbury (2005a).

CANTAB. The CANTAB was administered according to the user manual: instructions were read aloud and the tasks were presented on a tablet computer.

Planning. For the SOC task, the number of problems solved in the minimum number of moves, the initial thinking time and the subsequent thinking time were recorded.

Working memory. For the SSP task, span length was recorded. For the SWM task, strategy scores and double errors were recorded on 4-, 6-, and 8-box problems.

Flexibility. For the IED task, we were primarily interested in a participant's ability to switch from intra- to extra-dimensional sets in line with previous IED studies (Edgin & Pennington, 2005; Goldberg et al., 2005; Happe, Booth, Charlton, & Hughes, 2006; Hughes, Russell, & Robbins, 1994; Landa & Goldberg, 2005; Ozonoff et al., 2004; Yerys et al., 2009), hence we only report errors at stage 8 of this task (no group differences were detected at any other stage).

LB tasks. We employed the Embedded Figures Test (EFT, Spreen, 1969), a version which has not previously been used to assess local bias in individuals with ASD (see White & Saldana, 2011 for a recent review; cf. Children's Embedded Figures Test, Witkin, 1971). The stimuli consisted of 16 small pictures presented in book form and participants were required to locate a small, simple figure hidden in a larger figure and draw a line around the simple figure. Children were given two points on each trial for correctly identifying the hidden figure within 10 seconds and one point if this was completed after the time limit.

The Hooper Visual Organization Test (HVOT, Hooper, 1983), required the participant to combine fragmented puzzle-like pieces in their head and tell the experimenter what it would make as a whole. We recorded the number of correct answers and the average time for correct answers.

Results

As IQ and age varied greatly in these samples and both measures correlated to the majority of task measures, we chose to calculate individual performance levels for each task independent of IQ and age. We entered data from the NTD group as the dependent variable in a regression with FSIQ and age as the predictor variables, the resulting regression equation was applied to the ASD group, and residuals were collected for both groups. These were converted to z-scores in relation to the NTD group's mean and standard deviation and used in all further analyses. Deviant performance was defined as below the 5th centile of NTD group performance; to detect individuals in the ASD group with deviant performance on each measure, any NTD group outliers performing more than 1.65 standard deviations (SDs) below the NTD group mean were removed in order to obtain a better estimate of normal performance, regardless of NTD children who might have performed abnormally on any one task. The NTD group mean and SD were then recalculated and outliers were defined as those lying more than 1.65 new SDs below this new NTD group mean (White et al., 2006).

Theory of Mind (ToM)

The ASD group performed significantly worse than the NTD group on the mental state Strange Stories ($t(44)=3.10$, $p=0.003$). We did not find a significant difference between the groups on any other story type (ps>0.08). For the Frith-Happé Animations, we found significant group differences in both the appropriateness of the answers and intentionality in the ToM condition ($t(50.7)=4.63$ and $t(51.3)=4.28$, ps<0.001). The ASD group also gave less

appropriate answers in the GD condition ($t(66)=3.39$, $p=0.001$).

We found positive correlations between the mental state Strange Stories and both of the ToM scores from the Frith-Happé Animations ($r=0.326$, $p=0.007$ & $r=0.272$, $p=0.025$), although these did not hold in the groups separately. Nevertheless, we combined each individual's z-scores on these three ToM measures to create a total ToM performance score, first averaging the two Frith-Happé Animation ToM scores before averaging them with the Strange Stories mental state score. This ToM total score also revealed a significant group difference ($t(43.2)=5.253$, $p<0.001$) with the ASD group performing on average 2SDs below the NTD group mean (see figure 1). Scores can be seen to span the whole range of the NTD group performance but with an elongated tail of individuals performing particularly poorly; indeed, 58% of children in the ASD group fell below the 5th centile cut-off.

Figure 1 about here

Executive function (EF)

For generativity we found a significant group difference on Verbal Fluency in both conditions (letter, $t(65.7)=2.935$, $p=0.005$; category, $t(54.7)=2.358$ $p=0.022$), and on Pattern Meanings in the total number of correct responses ($t(63.3)=4.855$, $p<0.001$), with the ASD group performing more poorly. On the CANTAB tests, we found no significant group difference on any of the sub-scores in the SOC task (min. moves, $t(66)=1.107$, $p=0.272$; initial thinking, $t(66)=1.118$, $p=0.268$; sub thinking, $t(66)=0.060$, $p=0.952$), in the SSP task ($t(66)=0.252$, $p=0.802$), in the SWM task (number of errors in each condition, $t(66)<0.983$, ps >0.33; strategy used, $t(66)=0.691$, $p=0.492$) or in the IED task (extra dimensional shift, $t(66)=1.712$, $p=0.092$).

We found significant correlations between the letter condition in Verbal Fluency and the Pattern Meanings task ($r=0.428$, $p<0.001$), which held in the NTD ($r=0.338$, $p=0.041$) but not the ASD group ($r=0.287$, $p=0.117$). A total generativity score was calculated as the mean

of these three measures. Within the CANTAB, the SSP and the SWM tasks were correlated (r=0.293, p=0.015), which held in the ASD (r=0.517, p=0.003) but not the NTD group (r=0.088, p=0.606). A total mean CANTAB score was calculated, where each task was weighted equally. The total CANTAB and total generativity scores were then averaged to provide an EF total score.

The ASD group performed on average just less than 1SD below the NTD group on this EF total score (t(66)=3.856, p<0.001; see figure 1). The overall distribution was quite striking, however; there was significant overlap in the range of scores in the two groups. While 29% of children fell below the 5th percentile cut-off, the majority (52%) fell between this cut-off and the NTD group mean.

Local Bias (LB)

There was a non-significant tendency for children in the ASD group to perform slightly better than the NTD group on the EFT (t=1.924, p=0.059). In the HVOT, we did not find a significant group difference on the time taken to complete each trial (t=1.585, p=0.118) or on the credit score (t=1.567, p=0.122). Although there were no correlations between the two LB tasks, we combined the scores to give an LB total score, which did not differ significantly between the groups (t=0.094, p=0.925). Low z-scores indicated a local bias (high EFT and low HVOT scores). In the LB domain, only 13% of the children in the ASD group showed a profile indicative of a local processing style, falling below the 5th percentile cut-off.

Relationships between cognitive domains

We found no correlations between the composite scores of the three cognitive domains. Within ToM, performance on the Frith-Happé Animations was correlated to the EF composite (r=0.343, p=0.004) and, within EF, generativity was correlated to the ToM total score (r=0.299, p=0.013). These correlations seemed to be driven by an association specifically between the generativity composite and performance on the ToM Frith-Happé

Animations ($r=0.446$, $p<0.001$). These correlations generally did not hold in the groups separately, although there was a trend towards the latter association within the ASD group ($r=0.309$, $p=0.090$).

Patterns of impairment in each individual were studied. While the majority of children had a ToM impairment only, Figure 2 shows that individuals exist with most possible combinations of impairment. Figure 3 shows some specific examples of such combinations, portraying individual profiles across these three domains. This reveals that, although rare, the less frequent combinations of impairment are not an artefact of the cut-off methodology used; children exist with significant impairment in the affected domains whilst having retained performance in the remaining domains. Figure 2 further reveals a proportion of children with ASD who appear to have no significant cognitive impairments on the tests used here; 16% of children fell into this category although none had positive z-scores across all three cognitive domains.

Figures 2&3 about here

Wilks' discriminant function analysis was used to investigate which cognitive factors (ToM, LB or EF) were best able to predict group membership. Variables were entered and removed in a step-wise manner. ToM was the best discriminator, correctly classifying 74% of the children, and EF was found to significantly increase this discrimination to 79% ($\chi^2(2)=36.90$, Wilks' lambda=0.57, $p<0.001$; see classification matrix in Table 2; this increased further to 81% when the ToM Animations score and the Generativity Composite were substituted). Misclassification occurred equally in both groups, indicative of false negatives and false positives. When entered alone, EF classified 67% correctly. LB was not found to significantly aid in discriminating the groups at all.

Table 2 about here

Relationships between cognition and symptomatology

Relationships between cognitive and behavioural variables were explored in the ASD group alone as ADOS and ADI scores were not available for the NTD group. The ToM and EF total scores were unrelated to scores on the ADI but the LB total score was negatively correlated to a subscale of the ADI communication domain (delay in spoken language without attempts to compensate through gestures, $r=0.368$, $p=0.042$), indicating that the presence of autism-related communication symptoms was associated with a local processing bias (this would not withstand correction for multiple comparisons however). Likewise, ToM and EF total scores were unrelated to ADOS scores but the LB total score was correlated with a subscale of the ADOS repetitive behaviour domain (stereotypical behaviours, $r=0.398$, $p=0.027$), indicating that the absence of autism-related stereotypical behaviour was associated with a local processing bias (this would not withstand correction for multiple comparisons). We found no correlations between any of the cognitive domains and SRS scores, not even on a subscale level; likewise on the SCQ total scores.

Discussion

This case control study aimed to determine whether the cognitive impairments ToM, EF and LB are fractionable, and whether any of them are common to all individuals with autism spectrum disorders. Furthermore, we aimed to investigate whether these cognitive impairments predict autistic symptomatology, and whether the relationship between cognition and behaviour is dependent on the method of behavioural assessment.

We found that ToM and EF deficits differentiated those with ASD from neurotypically developing children at a group level and a proportion of individuals were characterised by each difficulty. In fact, these abilities together were able to correctly classify more than three-quarters of children into cases and controls. Furthermore, these cognitive impairments appeared to be related to each other, suggesting a lack of fractionation between these

domains. On the other hand, we found little support for the presence of an LB in autism, with only a small subgroup of individuals affected. Performance in this domain was unrelated to ToM and EF, indicating fractionation and that this processing style may explain specific aspects of autistic symptomatology that are present only in a small subgroup. However, we found no evidence that performance on ToM and EF tasks predicted autistic symptomatology regardless of the method of behavioural assessment.

Cognitive universality

Our ToM results at a group level are consistent with other studies of autism (Abell, Happe, & Frith, 2000; Castelli et al., 2002; Salter et al., 2008; White et al., 2009), including all those assessing performance across multiple cognitive domains (Brunsdon et al., 2014; Lai et al., 2012; Lam, 2013; Pellicano et al., 2006). Despite great diversity in the tasks and methods used, ToM is consistently found to be impaired. Further, we found here that 58% of children with autism performed within the bottom 5th centile of neurotypical performance, and that ToM alone was able to correctly classify 74% of children into the correct groups and hence predict diagnostic status. This indicates that the ToM impairment may be the most frequently-occurring, well-specified and robust impairment, as well as being clinically relevant. It is possible that with even more sensitive tests (e.g. Senju, Southgate, White, & Frith, 2009), a ToM impairment might well be a universal impairment in autism.

Likewise, EF impairment also seems to be quite reliably identified across studies (for reviews, see: Hill, 2004; Russo et al., 2007), including in 4 out of 5 cross-domain studies (the present study included). There appears to be an attenuating effect across EF tasks however: only a proportion of tasks produce group differences in each study and there is variability in which tests give rise to group differences across studies (Russo et al., 2007). Here, our significant group difference in the EF domain was largely driven by the poor performance of the ASD group on the generativity tasks (which support previous findings on generativity,

Ambery, Russell, Perry, Morris, & Murphy, 2006; Bishop & Norbury, 2005b; Turner, 1999). Indeed, no single test from the CANTAB battery or the combined performance on the CANTAB tasks reached statistical significance, a finding that is not unusual in past CANTAB studies of ASD (Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; Goldberg et al., 2005). One possible explanation lies in the computerised administration of the CANTAB; it has been proposed that a participant's ability to infer the experimenter's intentions may affect test performance in an experimenter-administered situation (see Kenworthy, Yerys, Anthony, & Wallace, 2008; S. J. White, 2013), although Williams and Jarrold (2013) have recently published evidence to the contrary. Another possibility is that the verbal nature of the generativity tasks, rather than the EF properties, posed a problem for the children with ASD.

Despite this, the combined EF measure still placed 29% of children with ASD in the bottom 5th centile of neurotypical performance, and significantly strengthened the group classification algorithm. Furthermore, the EF measure alone was able to correctly classify 67% of children into the correct diagnostic groups, indicating that our 5th centile cut-off technique may have been overly conservative. An EF impairment certainly appears to be present in a substantial subgroup of individuals with autism therefore.

The presence of an LB in autism has the weakest support both from the general autism literature (Happe & Frith, 2006) as well as from cross-domain studies (2 out of 5 studies, the present study included); even when significant effects are identified, it remains unclear whether these are mostly driven by an enhancement in local processing or a deficit in global processing. Our finding of a non-significant trend for enhanced local processing is certainly within the range of previous results. The lack of effect on the global processing task used here could be due to the choice of task and instructions given; it is possible that participants were able to identify the object by looking at a single piece rather than attempting to combine

the pieces. This possible pitfall could have been avoided by using the modified version of the task (Jolliffe & Baron-Cohen, 2001) where the combined picture cannot be interpreted from the fragments. Together, our tasks classified only 13% of the current sample of children as displaying an LB. If an LB is present in only a small subsample of the autistic population, this would go some way to explain the lack of group differences that are often reported in this domain.

Cognitive fractionation

Across the cognitive functions, measures were generally unrelated, most possible combinations of impairment were found in different children with ASD, and individual profiles revealed double dissociations between cognitive domains. While this generally paints a picture of cognitive fractionation in autism, we did find a strong relationship specifically between generativity and ToM performance on the Frith-Happé animations; ToM and EF also classified very similar sets of children into those with and without autism. It seems likely that these specific ToM and EF tests were related here either due to overlapping task demands (cf. verbal tasks and tasks requiring inference of the experimenter's intentions) or because these two cognitive processes fundamentally rely on a common cognitive mechanism. Despite a lack of clarity as to the roots of this association, the past literature in ASD certainly supports the existence of such a relationship (Joseph & Tager-Flusberg, 2004; Ozonoff, Pennington, & Rogers, 1991; Zelazo, 2002).

Cognition to behaviour

To the best of our knowledge, only one study (Pellicano et al., 2006) has previously assessed correlations between multiple cognitive domains and symptomatology, and the few associations they found failed to survive correction for multiple comparisons. Even though we included multiple measures that probed behavioural symptomatology in different ways, associations between cognitive performance and behavioural symptomatology in the present

study were similarly sporadic and weak. Surprisingly, LB was the only domain that was correlated with symptomatology, being associated with less stereotypical behaviours on the ADOS and delay in spoken language without attempts to compensate through gestures on the ADI-R. These correlations were unexpected and did not survive Bonferroni correction.

This lack of association across multiple methodologies and across two studies now, raises the question of the construct validity of the behavioural and cognitive test measures. While both clearly differentiate the autistic from the neurotypical group, it is possible that tests at either or both levels of representation are tapping into variance in some factor orthogonal to the one intended. Behavioural measures are intrinsically liable to the subjective opinion of the parent, teacher or experimenter, and the behaviours of interest are susceptible to being overshadowed by individual differences in intelligence, language, personality, education etc. Cognitive measures are likewise rarely pure measures of a single cognitive process. Recent work looking at more implicit cognitive measures (Schuwerk, Vuori, & Sodian, 2015; Senju, 2012; Sodian & Thoermer, 2008) holds promise for tapping more directly into the cognitive impairments underlying autism.

In summary, our multi-domain study of cognition in autism indicated that difficulties on ToM and EF tasks characterise the majority of cases, raising the possibility that one or both may after all prove to be universal in autism given more sensitive cognitive measures. If so, this would counter the idea of 'the autisms' at least at the cognitive level and indicate that the spectrum should be approached as a unitary disorder. Our results also contribute to understanding fractionation in autism: ToM and EF were related, although the exact nature of this association has yet to be determined. ToM and EF were also the only variables to display clinical relevance, together distinguishing the vast majority of cases from controls, despite a lack of specific associations between cognitive and behavioural measures. While an LB

appears to be fractionated from ToM and EF, it was detected in only a few children and did
not improve diagnostic classification, most likely contributing to non-diagnostic symptoms in
a subgroup. Despite the characteristic heterogeneity of the autism spectrum, it remains a
possibility therefore that a single cognitive cause may underlie the range of diagnostic
symptoms in all individuals with autism.

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Table 1: Participants characteristics; means (with standard deviations)

	ASD group	NTD group
N (Male:Female)	31 (25:6)	37 (26:11)
Age	10.98 (1.37)	10.87 (1.33)
Performance IQ	102.06 (18.10)	108.59 (18.22)
Verbal IQ	104.77 (13.94)	102.57 (16.30)
Parents' educational level (higher:lower)	19:12	25:12
SCQ[a], parents***	16.74 (7.30)	3.09 (2.39)
SCQ[b], teachers***	12.81 (5.54)	6.83 (3.31)
SRS[c], parents***	91.41 (30.99)	19.51 (12.09)
SRS[d], teachers***	71.90 (28.22)	16.84 (13.04)
ADOS total	9.90 (3.67)	-
ADI total	30.39 (14.26)	-

[a] N=31:33

[b] N=27:23

[c] N=29:33

[d] N=20:26

*** $p < 0.001$

Table 2: Classification matrix for the discriminant function analysis, showing the percentage

of correct classifications according to ToM and EF composite scores.

		Predicted group	
		ASD	NTD
Actual group	ASD	77.4%	22.6%
	NTD	18.9%	81.1%

Figure 1: The individual performance for both groups (ASD and NTD); each line represents one individual's z-score on the given domain and the dotted lines indicates the bottom five per cent in the NTD group. Children in the ASD group below the dotted line were classified as "poor" performers.
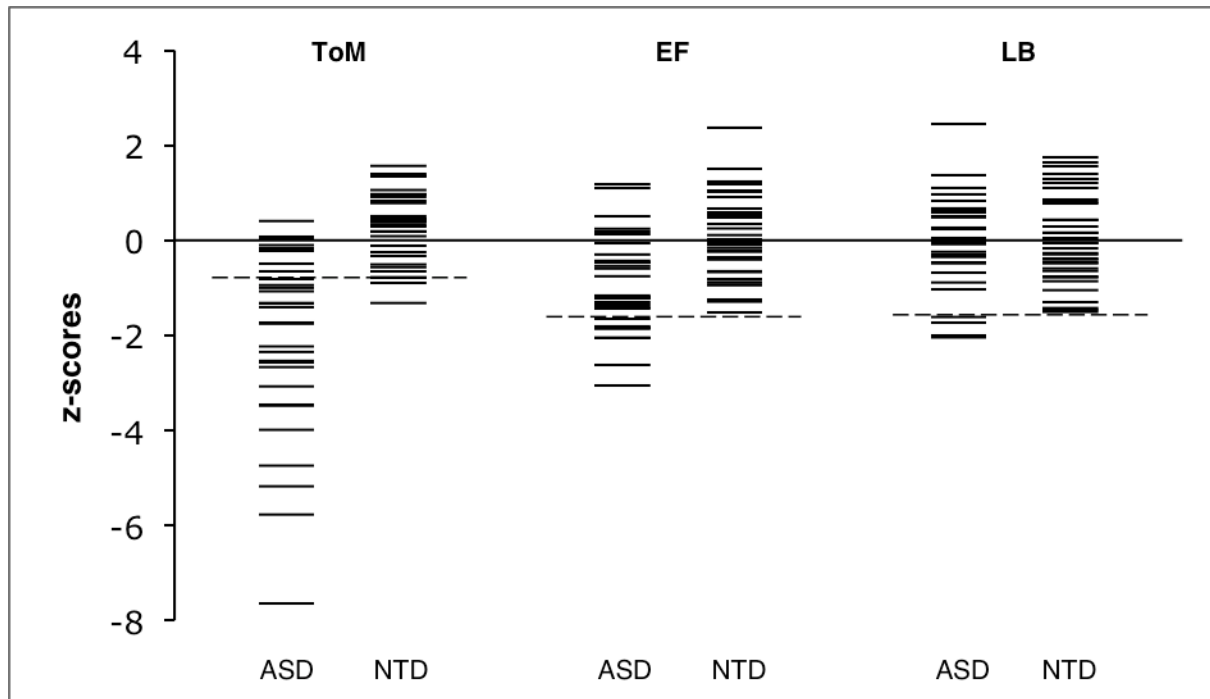
Figure 2: Venn diagram to show the number of children with ASD who displayed significant ToM, LB or EF impairments; the 5 children outside the diagram represent those in which none of these impairments were detectable.
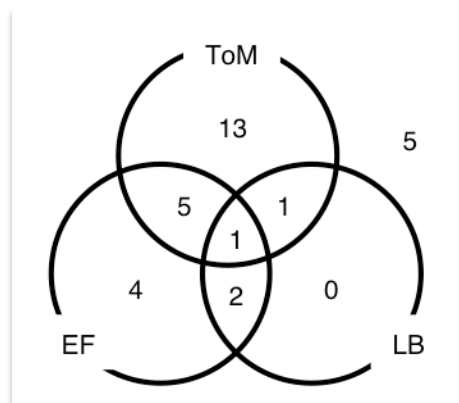
Figure 3: Profiles for children with ASD showing the presence of seven out of eight possible combinations of impairment and double dissociations between these three cognitive domains.