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Social analogical reasoning in school-aged children with autism spectrum disorder and typically developing peers

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Abstract

Analogical reasoning is an important mechanism for social cognition in typically developing children, and recent evidence suggests that some forms of analogical reasoning may be preserved in autism spectrum disorder. An unanswered question is whether children with autism spectrum disorder can apply analogical reasoning to social information. In all, 92 children with autism spectrum disorder completed a social content analogical reasoning task presented via photographs of real-world social interactions. Autism spectrum disorder participants exhibited performance that was well above chance and was not significantly worse than age- and intelligence quotient–matched typically developing children. Investigating the relationship of social content analogical reasoning performance to age in this cross-sectional dataset indicated similar developmental trajectories in the autism spectrum disorder and typically developing children groups. These findings provide new support for intact analogical reasoning in autism spectrum disorder and have theoretical implications for analogy as a metacognitive skill that may be at least partially dissociable from general deficits in processing social content. As an initial study of social analogical reasoning in children with autism spectrum disorder, this study focused on a basic research question with limited ecological validity. Evidence that children with autism spectrum disorder can apply analogical reasoning ability to social content may have long-range applied implications for exploring how this capacity might be channeled to improve social cognition in daily life.

Keywords

analogy, autism spectrum disorder, development, social cognition

When a child steps onto a field for the first soccer practice of his life, he sees a semi-circle of children facing an adult who is talking. The people are new and the shoes feel strange, but the situation soon begins to seem familiar. Being at soccer practice with his coach and teammates is similar to being at school with his teacher and classmates. The similarity helps him understand what to do and what to expect others to do. Understanding the abstract (i.e. non-literal) similarities between seemingly different situations, especially social situations, is often accomplished through a form of reasoning called analogical reasoning (Gentner and Medina, 1998; Green et al., 2010, 2012; Holyoak and Thagard, 1995; Landau et al., 2010; Read, 1987; Smith, 1984; Spellman and Holyoak, 1992). In this way, analogical reasoning plays a critical role in social learning via social schema development, helping children successfully cope with social interactions (Holyoak and Gordon, 1984; Landau et al., 2010; Read, 1987; Smith, 1984).

Children with autism spectrum disorder (ASD) have difficulty understanding and coping with unfamiliar situations, especially social situations (Klin et al., 2003). Intriguingly, children with ASD have demonstrated strong reasoning abilities in several tasks (Bolte et al., 2009;

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Hayashi et al., 2008). Research with nonsocial analogies shows that analogical reasoning may be intact in children with ASD without intellectual disability (Green et al., 2014; Morsanyi and Holyoak, 2010; Scott and Baron-Cohen, 1996). Encouraging evidence in a small cohort of adults, but not children, with ASD showed successful performance on analogies that involved relations between drawings of living things (Krawczyk et al., 2014). In a recent study, when children with ASD were explicitly instructed to use analogical reasoning, they performed as well as typically developing children (TDCs) on a task that required them to find abstract similarities in spite of superficial differences, for example, basketball is to hoop as envelope is to mailbox (Green et al., 2014).

A critical unknown is whether the capacity for analogical reasoning in children with ASD can be successfully used to process social content; it is social content that typically presents the greatest challenge for children with ASD (Dawson et al., 1998). If children with ASD can successfully apply analogical reasoning to social content, this would help to inform understanding of social analogical reasoning on both theoretical and applied levels. At the theory level, it would suggest that social analogical reasoning may be a metacognitive skill that can function at least somewhat dissociably from general deficits in social content processing. At the applied level, evidence of the capacity for social analogical reasoning in children with ASD would set the stage for ecologically valid investigating whether strategies that encourage analogical reasoning might augment interventions to improve on real-world social cognition deficits. Here, we tested the hypothesis that children with ASD can employ analogical reasoning to understand abstract similarities between social interactions. Social interactions were depicted in real-world photographs. While still far from a truly ecologically valid paradigm, the use of real-world photographs was intended to increase the ecological validity of information processing relative to prior studies of analogical reasoning in ASD that have employed line drawings (Krawczyk et al., 2014; Morsanyi and Holyoak, 2010; Scott and Baron-Cohen, 1996), thus bolstering our primary aim of investigating analogical reasoning about social interactions in children with ASD.

Analogical reasoning in ASD is still only sparsely characterized, and a key unexplored area is the developmental trajectory of analogical reasoning over the course of childhood. In this study, a large sample of 92 children with ASD, spanning a broad range of development (from ages 8 to 17 years), enabled us to investigate whether and how social content analogical reasoning improved during childhood in ASD. A sample of 41 TDCs allowed for age- and intelligence quotient (IQ)-matched comparisons of social content analogical reasoning and its developmental trajectory between children with ASD and their typically developing peers.

Table 1. Demographics for full set of ASD participants.

N	92
Age (years)	
M (*SD*)	11.08 (2.23)
Range	8.0–17.47
Full-scale IQ[a]	
M (*SD*)	105.58 (18.11)
Range	66−149
Sex (female/male)	16/76
ADOS	
Social affect	
M (*SD*)	10.08 (3.98)
Restricted, repetitive behavior	
M (*SD*)	2.87 (1.56)

ADOS: Autism Diagnostic Observation Schedule–Module 3; ASD: autism spectrum disorder; SD: standard deviation; IQ: intelligence quotient.
[a]Differential Abilities Scale–2nd Edition, Wechsler Intelligence Scale for Children–4th Edition, Wechsler Abbreviated Scale of Intelligence, or Wechsler Abbreviated Scale of Intelligence–2nd Edition.

Materials and methods

Participants

A total of 92 children with ASD (age: $M = 11.05 \pm 2.23$ years; 76 males) and 41 TDCs (age: $M = 11.08 \pm 2.32$ years; 26 males) were recruited (see Table 1 for full ASD demographics). Participants were primarily middle- and upper-class children (70% Caucasian) recruited from the suburbs of Philadelphia and Washington, D.C.

For comparisons of ASD to TDC performance, each TDC participant was matched with an ASD participant within 12 months of the TDC participant's age, and we confirmed that matched groups did not differ in IQ. Table 2 displays demographics for TDCs and matched ASD participants, including *p* values for between-group comparisons. For inclusion in the study, participants were required to have full-scale IQ scores $\geqslant 60$. Written informed consent from parents of children and assent from children were obtained according to Institutional Review Board guidelines. Study procedures were approved by the Children's Hospital of Philadelphia Institutional Review Board, the Institutional Review Board within the Office for the Protection of Human Subjects at Children's National Medical Center, and the Georgetown University Institutional Review Board.

Diagnosis/screening procedures

Children with ASD received a clinical diagnosis based on *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text revised; American Psychiatric Association (APA), 2000). ASD diagnoses were confirmed with the autism diagnostic observation schedule (ADOS; Lord et al., 2000), and the Autism Diagnostic Interview–Revised

Table 2. Demographics for TDCs and matched ASD participants.

	TDC	ASD	*p* value
N	41	41	
Age (years)			
M (*SD*)	11.08 (2.32)	10.98 (2.24)	0.840
Range	7.33–17.00	8.00–16.72	
Full-scale IQ[a]			
M (*SD*)	116.32 (13.58)	115.32 (14.95)	0.752
Range	88–149	88–149	
Sex (female/male)	15/26	10/31	0.230

ASD: autism spectrum disorder; SD: standard deviation; IQ: intelligence quotient; TDC: typically developing children.
[a]Differential Abilities Scale–2nd Edition, Wechsler Intelligence Scale for Children–4th Edition, Wechsler Abbreviated Scale of Intelligence, or Wechsler Abbreviated Scale of Intelligence–2nd Edition.

(Lord et al., 1994) by research reliable clinicians. Scores for Social Affect and Restricted and Repetitive Behaviors were calculated for ADOS (Gotham et al., 2007). Children with ASD were screened through a parent phone interview and excluded if their legal guardians reported any history of known genetic, psychiatric, or neurological disorders (e.g. Fragile X syndrome, psychosis, or Tourette's syndrome). Stimulant medications were withheld at least 24 h prior to testing ($n=11$) in accordance with standard practices (Greenhill, 1998), while other longer term medications were not withheld for ethical reasons (selective serotonin reuptake inhibitors $n=9$; selective norepinephrine reuptake inhibitors $n=4$; α2A agonists $n=3$; melatonin = 5). TDC children were screened and excluded if they or a first-degree relative had developmental, language, learning, neurological, psychiatric disorders, medical disorders affecting cognition, or psychiatric medication usage, or if the child met the clinical criteria for a childhood disorder on the Child Symptom Inventory–4th Edition or Child and Adolescent Symptom Inventory (Gadow and Sprafkin, 2010). One TDC child was enrolled but excluded due to the presence of a significant sleep disorder discovered during testing. Two children (1 ASD; 1 TDC) received Wechsler Intelligence Scale tests (Wechsler Intelligence Scale for Children–4th Edition, or Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999, 2003)) within the last year so these prior IQ scores were included. Subsequent to screening, IQ records could not be retrieved for two ASD participants so these participants were excluded from the matched ASD-TDC group and from any analyses involving IQ.

Task stimuli and procedures

A total of 20 social content analogy trials were viewed on a computer screen (Figure 1; a complete list of stimuli is provided in Supplementary Table 1).

In each trial, a picture of a *social interaction* appeared at the top of the screen. Participants were instructed to choose which of the four pictures appearing below was the best analogical match for the top picture (which one shows the "same kind of interaction"). Because our sample included relatively young children and children with relatively low IQs, the experimenter was careful to ensure that children understood all instructions, and explicitly talked to children about the meaning of the word, "interaction," if they had any uncertainty. Distractor images of non-analogous interactions were devised for each trial to ensure that relying solely on semantic association or visual similarity would not yield above chance accuracy. Specifically, one distractor image in each trial was devised to be semantically associated with the picture at the top of the screen, and another distractor item was devised to be visually similar to the image at the top of the screen. For example, when the image at the top of the screen depicted a man helping another man tie his necktie near a tree, the semantic distractor image depicted a tuxedo, while the visual distractor depicted an image of two people near trees that the authors judged to have similar overall visual composition to the item at the top of the screen. A third, non-associate distractor item was included on each trial, which depicted a social interaction that the authors judged was not strongly associated with the image at the top of the screen (e.g. for the trial with the necktie tying image at the top of the screen, the non-associate distractor depicted people jumping into a lake together). Before beginning the task, participants were explicitly instructed about what an analogy is and how to apply analogical reasoning (see Supplementary Materials). All participants had been previously exposed to analogies in a nonsocial task as part of a separate study before beginning the social analogies task, which helped ensure that participants had a basic familiarity with how to explicitly apply analogical reasoning.

Stimuli were devised in our laboratory to represent a range of different social interactions and involved both children and adults although the majority of stimuli depicted children. Accuracy and response time (RT) were recorded for each task trial. E-prime software failed to record RT for two TDC participants, but accuracy data were recorded and included in our analyses. To confirm the validity of the analogy stimuli, a pilot group of 96 adult subjects in the United States performed the analogical reasoning task via Amazon Mechanical Turk, six of whom were removed from analysis because they did not complete the task. Item analysis showed that the pilot group identified the intended correct answer with high accuracy ($M=89.53\%$, standard deviation (SD) $=14.70\%$). Items were not included in the main study analysis if pilot group accuracy was more than two standard deviations below the pilot mean. This resulted in the removal of one stimulus item.

Results

Accuracy for social content analogies in the full set of 92 ASD participants was well above chance ($M=77.12 \pm SD=25.22\%$; chance performance in this

Figure 1. An example pictorial analogy item used in the social content analogical reasoning task. Participants were explicitly instructed to apply analogical reasoning to identify the correct response from four possible answer choices. Each trial required participants to identify analogies between social interactions, that is, mutually voluntary interactions between intentional agents (usually people, occasionally animals).

task is 25% accuracy), with an average RT of 7418 ± 3576 ms. Social content analogies accuracy was correlated with age ($r = 0.43$, $p < 0.001$) and IQ ($r = 0.37$, $p = 0.001$). We did not emphasize responding quickly in the task instructions so associations with RT were not strongly predicted. It was thus not surprising that neither age nor IQ was correlated with RT for social content analogies (both $p > 0.200$). Accuracy and RT were not related to each other ($r = 0.02$, $p = 0.828$), indicating that there was not a speed–accuracy tradeoff. Table 3 displays zero-order correlations between variables collected in the full set of 92 ASD participants.

Comparison between ASD and TDC performance was undertaken in the 82 matched participants (41 ASD; 41 TDC). Mean accuracy on social analogies for children with ASD in the matched sample was 86.01% ± 16.38% with an RT of 7246 ± 2229 ms; TDCs were 90.63% ± 13.80% accurate with an RT of 6893 ± 2060 ms. Table 4 displays zero-order correlations between variables collected in the TDC sample.

Accuracy was compared between the diagnosis groups, using age and IQ as covariates in order to distinguish any effects of ASD diagnosis from effects of age and IQ. This model showed that, while TDC participants appeared to be somewhat more accurate, there was no significant effect of diagnostic group on social content analogies accuracy ($F(1,78) = 1.84$, $p = 0.179$, $\eta^2 = 0.02$). Age ($F(1,78) = 12.42$, $p = 0.001$, $\eta^2 = 0.14$), but not IQ ($F(1,78) = 0.76$, $p = 0.385$, $\eta^2 = 0.01$) showed effects on social content analogies accuracy in this model. A simple t-test also showed no significant difference in social analogies accuracy between groups ($t(80) = 1.38$, $p = 0.171$, Cohen's $d = 0.31$). Rerunning these between-group contrasts with RT in place of accuracy also revealed no differences between the ASD and TDC groups (both $p > 0.200$). In the matched samples, 14 TDCs and 10 ASD participants performed at ceiling, with older participants in both groups showing more frequent ceiling performance. This was not unexpected because we devised our task to be suitable for a large group that included young children and children with low IQ in the full ASD cohort of 92 participants. To test whether potential ceiling effects explained the lack of differences between groups in social content analogies accuracy, we compared the matched groups after removing individuals who performed at ceiling (i.e. only including participants with accuracy < 95%). As in the original model, there was no significant effect of diagnosis group ($F(1,54) = 1.30$, $p = 0.260$, $\eta^2 = 0.02$). Again, age ($F(1,54) = 8.04$, $p = 0.006$, $\eta^2 = 0.13$), but not IQ ($F(1,54) = 1.46$, $p = 0.232$, $\eta^2 = 0.03$), showed an effect. Again, a direct t-test also showed no difference in social analogies accuracy between diagnosis groups ($t(56) = 1.03$, $p = 0.307$, Cohen's $d = 0.28$).

Table 3. Zero-order correlations for variables in the full ASD dataset.

	Age	Analogies accuracy	Analogies RT	IQ
Age				
r	1			
p				
Analogies accuracy				
r	0.43	1		
p	>0.001			
Analogies RT				
r	−0.13	0.023	1	
p	0.218	0.828		
Analogies IQ				
r	−0.08	0.37	0.05	1
p	0.481	>0.001	0.661	

RT: response time; IQ: intelligence quotient; ASD: autism spectrum disorder.

Table 4. Zero-order correlations for variables in the TDC dataset.

	Age	Analogies accuracy	Analogies RT	IQ
Age				
r	1			
p				
Analogies accuracy				
r	0.41	1		
p	0.009			
Analogies RT				
r	−0.31	0.09	1	
p	0.054	0.572		
Analogies IQ				
r	−0.27	0.08	−0.03	1
p	0.083	0.643	0.856	

RT: response time; IQ: intelligence quotient; TDC: typically developing children.

To investigate whether performance on the social analogies task was associated with our measures of ASD phenotype, we tested correlations between outcome measures for the social analogies task and the ADOS Social Affect and Restricted and Repetitive Behaviors subscale scores. Correlations were tested in both the full sample of ASD participants and the subset of 41 ASD participants included in the TDC-matched analyses. Correlations were investigated for both social analogies accuracy, which was our primary outcome measure, and for RT in the social analogies task. These models indicated no significant correlations (all $r < 0.1$; all $p > 0.350$).

As noted above, in the full set of 92 ASD participants, age was strongly correlated with social analogies accuracy. Regressing social analogies accuracy on age and IQ indicated an IQ-independent increase in social analogies accuracy over the developmental range we sampled ($\beta = 0.44$, $t(89) = 5.06$, $p < 0.001$; Figure 2). IQ was also significantly predictive in this model ($\beta = 0.41$, $t(89) = 4.64$, $p < 0.001$).

The model yielded a trajectory of IQ-independent increase in accuracy across ages that appeared roughly linear overall, but with the steepest increase in accuracy among the younger ages sampled. Rerunning the model with a quadratic specification of age included as a regressor, along with age and IQ, indicated that the quadratic specification explained a significant amount of variance ($\beta = -2.12$, $t(89) = -2.88$, $p < 0.005$), while both age and IQ remained significantly predictive in this model (both $p \leq 0.001$). Concordantly, a quadratic function reflecting a steeper slope at younger ages was a better fit to the data ($R^2 = 0.55$) than a linear function ($R^2 = 0.51$). Confirmatory analyses to account for potential ceiling effects showed that the correlation between age and social analogies accuracy remained significant after removing ceiling performers ($r = 0.45$, $p < 0.001$), as did the effect of age in the regression model including IQ as a covariate ($\beta = 0.53$, $t(73) = 5.49$, $p < 0.001$). To elucidate the developmental trajectory of social analogical reasoning in ASD relative to typical development, we compared correlation coefficients and

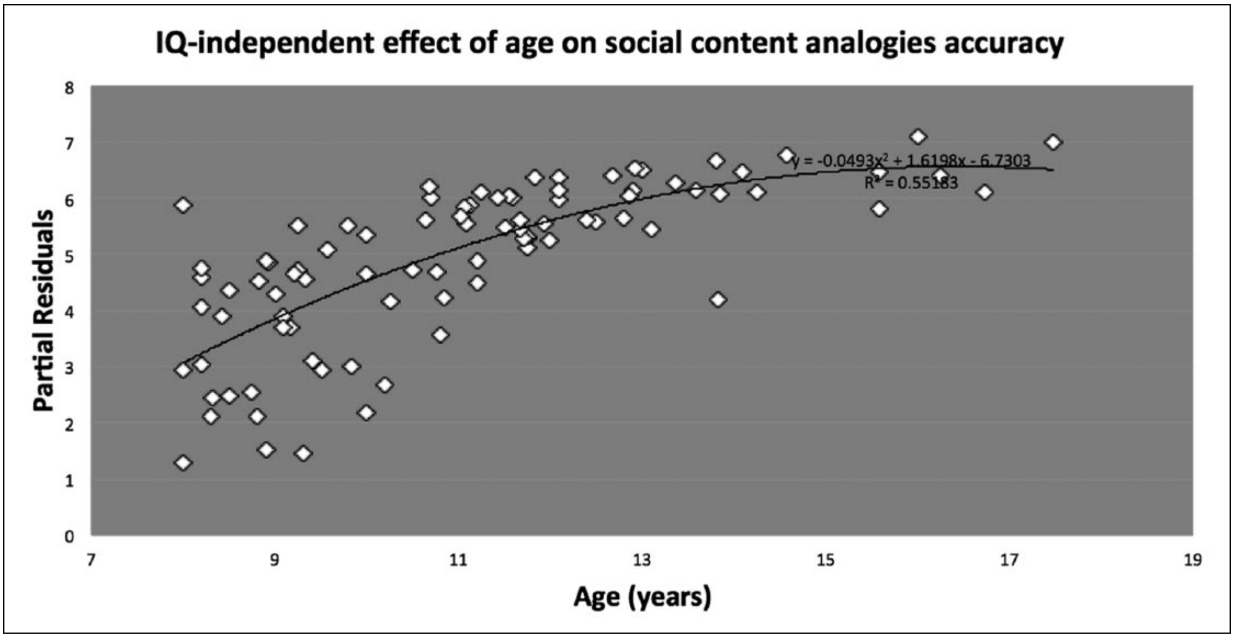

Figure 2. Partial residual plot representing the relationship between age and social content analogies accuracy after accounting for the effect of IQ. Partial residuals reflecting the predictive value of age for social content analogies accuracy were derived from a regression model in which social content analogies accuracy was regressed on both age and IQ. The trend line represents a quadratic function that was a good fit to the data, indicating a sharper increase in social content analogies accuracy in the earlier years of development.

slopes for the relationship between age and accuracy in the matched TDC and ASD groups. Correlations between age and accuracy were observed on both groups (TDC: $r=0.41$, $p=0.009$; ASD: $r=0.33$, $p=0.037$), and both groups showed IQ-independent effects of age on social content (TDC: $\beta=0.46$, $t(38)=3.05$, $p=0.004$; ASD: $\beta=0.33$, $t(38)=2.13$, $p=0.040$). Although quadratic functions were nominally better fits to this IQ-independent relationship than linear functions in each matched group, adding a quadratic specification of age as a regressor did not explain significant additional variance in the ASD ($\beta=-1.75$, $t(37)=-1.30$, $p=0.201$) or TDC ($\beta=-1.65$, $t(37)=-1.40$, $p=0.169$) model. Comparison of Pearson correlation coefficients via Fisher's r-to-z transformation indicated no difference ($z=0.40$, $p=0.689$). Comparison of the slopes derived from the respective regression models for each group revealed no difference ($t(78)=0.21$, $p=0.788$). The intercepts for the models in the two groups also did not differ ($t(78)=0.82$, $p=0.415$). Confirmatory correlation and regression models with ceiling performers removed showed that the effect of age remained significant in each model at a nominal $\alpha=0.05$ level, and removing ceiling performers also yielded no differences in correlation coefficients, slopes, or intercepts (all $p>0.250$).

To test for differential effects of different distractor types between ASD and TDC participants, comparison of error response rates for each distractor type was undertaken in the matched ASD and TDC samples. Mean error response rates for distractor types were as follows: semantic (overall: 6.47%±6.39%; ASD: 7.01%±7.16%; TDC: 5.90%±5.49%); visual (overall: 2.75%±3.37%; ASD: 3.17%±3.40%; TDC: 2.31%±3.31%); non-associate (overall: 1.28%±2.29%; ASD: 1.59%±2.84%; TDC: 0.96%±1.48%). A 2 (group: ASD, TDC)×3 (distractor type: semantic, visual, and non-associate) mixed analysis of variance (ANOVA) indicated a main effect of distractor type, $F(2,77)=31.14$, $p<0.001$, $\eta^2=0.45$. Critically, however, this model indicated no main effect of diagnosis group, $F(1,78)=1.34$, $p<0.251$, $\eta^2=0.02$, and no interaction of group by distractor type, $F(2,77)=0.08$, $p=0.923$, $\eta^2<0.01$. Thus, while there was a difference between error response rates for distractor types, with semantic distractor error response rates being highest, different distractor types did not appear to differentially affect the performance of children with ASD versus their typically developing peers. This was confirmed by a chi-square model that compared the frequency of error responses for each trial type among matched ASD and TDC participants, $\chi^2(2)=2.57$, $p=0.276$. We also tested whether error rates for different distractor types showed differential associations with age in the two diagnosis groups. Rates of errors showed negative associations with age for all three distractor types: semantic ($r=-0.369$, $p<0.001$), visual ($r=-0.331$, $p=0.001$), and non-associate ($r=-0.207$, $p=0.047$). However, associations with age did not differ between ASD and matched TDC participants for semantic ($z=0.22$, $p=0.826$.), visual ($z=0.29$, $p=0.772$), or non-associate ($z=0.41$, $p=0.682$) distractor types.

Discussion

This study is the first to our knowledge to focus on analogical reasoning about social content in children with ASD. A total of 92 children with ASD spanning a large developmental range performed a social content analogical reasoning task at above chance accuracy and showed IQ-independent increases in accuracy across childhood in our cross-sectional sample. Comparison of a subset of children with ASD to age- and IQ-matched TDCs indicated similar performance on the social analogical reasoning task between groups, and that accuracy increased on a similar cross-sectional developmental trajectory in both groups. These findings generally indicate the presence of an as yet underexplored capacity for children with ASD to apply analogical reasoning ability to social content. This work extends previous research that has primarily focused on nonsocial analogical reasoning in ASD (Green et al., 2014; Morsanyi and Holyoak, 2010; Scott and Baron-Cohen, 1996) and begins to characterize the developmental trajectory of social analogical reasoning, albeit cross sectionally. The use of photographic stimuli depicting real people engaging in social interactions is also a step toward more ecologically valid information processing relative to line drawings and cartoon images that have generally been used in studies of analogical reasoning in ASD and TDCs (Krawczyk et al., 2014; Morsanyi and Holyoak, 2010; Scott and Baron-Cohen, 1996). Although this study is not ecologically valid as a measure of cognition in real-world social situations, improving the ecological validity of information processing in laboratory tasks as much as possible is nonetheless helpful for better understanding of social analogical reasoning and social cognition more generally.

The present evidence that analogical reasoning can support successful identification of similarities between social interactions, even when other social abilities are impaired, informs theoretical understanding of social analogical reasoning as a metacognitive ability that may be at least partially dissociable from general social content processing ability. Although analogical reasoning has been linked to social cognition (Landau et al., 2010; Read, 1987; Smith, 1984), prior research has only considered typically developing populations. Thus, it has not been clear whether the application of analogical reasoning to social content relies on the presence of other social abilities (e.g. emotion recognition, empathy, theory of mind, pragmatic language) that contribute to typical social function, or whether social analogical reasoning is at least a partially discrete metacognitive tool. The present data provide an initial indication that analogical reasoning may have some utility for understanding social interactions even in those with social cognition deficits (recall that the ASD diagnosis/screening protocol confirmed general impairment of social abilities, which can include theory of mind).

If children with ASD can use analogical reasoning to process social content, why don't they use it as effectively as TDCs to support social cognition in daily life? There are likely many factors that contribute to the difficulties children with ASD encounter in social cognition. For analogical reasoning, one relevant consideration may be the distinction between spontaneous versus effortful analogical reasoning (Gick and Holyoak, 1983). While poor understanding of novel social interactions suggests that children with ASD do not frequently use social analogical reasoning spontaneously, the present data indicate that they are capable of effortfully using analogical reasoning to find similarities between social situations when they are explicitly instructed to use an analogical approach, at least in a laboratory setting on a highly structured and repetitive task. This result coheres with prior evidence that explicit instruction can reveal otherwise latent/hidden abilities in children with ASD. For example, while children with ASD generally display an attentional bias toward local processing (i.e. focus on individual details rather than the big picture (Happe and Frith, 2006), there is an evidence that children with ASD are capable of overcoming their bias to detail if their attention is explicitly directed to global information (Happe and Frith, 2006; Plaisted et al., 2003). Children with ASD performed well in global processing tasks in studies of divided attention (Plaisted et al., 1999) and letter string discrimination (Plaisted et al., 2003) after their attention was explicitly directed toward the global information in these tasks. Children with ASD were much less likely than TDCs to spontaneously see both forms in an ambiguous figure (e.g. rabbit/duck), but they were fully able to see both forms after they were explicitly directed to look for two forms (Sobel et al., 2005).

Data from this study begin to delineate the developmental trajectory of social content analogical reasoning in children with ASD, indicating an increase in accuracy throughout the school-aged years. These data may help to connect two lines of evidence concerning the developmental trajectories for social versus reasoning-related abilities in children with ASD. Whereas non-reasoning-related social abilities in children with ASD fall substantially behind TDC peers in the school age childhood years (Happe et al., 2006; Klin et al., 2007; O'Hearn et al., 2010), reasoning-related abilities exhibit less of a plateau in children with ASD (Happe et al., 2006; Luna et al., 2007). The present data thus provide an initial indication that analogy use in the second decade of life may provide some degree of opportunity for social learning and possibly improved social function during a critical period of development.

Contributing to the groundwork for therapeutic intervention

A challenge for ASD research is to find ways to channel the capabilities that are already present in ASD to address core deficits. The position of analogy at the nexus of reasoning and social cognition, especially for understanding social interactions (Green et al., 2014; Holyoak and Thagard, 1995; Landau et al., 2010; Read, 1987; Smith, 1984) indicates a theoretical basis for this kind of approach to ASD therapy. To our knowledge, the extent to which children with ASD can use analogical reasoning to process social content has not previously been explored. Interestingly, some therapists who work with children on the autism spectrum have identified the potential utility of analogical reasoning and have begun using analogical reasoning in therapy games (http://www.nationalautismresources.com/analogies-game.html). However, very little empirical data are available to validate or guide this therapeutic approach. The present evidence of intact social content analogical reasoning in ASD, at least in a laboratory task, contributes to an empirical foundation for social content analogical reasoning applications in ASD. The applied implications of this study are quite long range, but are interesting as an initial study of analogical reasoning about social content in children with ASD. Further empirical understanding of social analogical reasoning in ASD may lead to experimental investigations that target strategies to augment existing analogical reasoning abilities in ASD with the goal of testing potential improvements in real-world social cognition.

Limitations of this study

In interpreting the present data, it is important to acknowledge the difficulty of definitively classifying the content of stimuli as social, and that the construct of social cognition is generally difficult to operationalize. Mutually voluntary interactions between intentional agents (usually people, occasionally animals) constituted social content in our stimuli. Social cognition in ASD is characterized by a multifaceted collection of social processing deficits, including interpretation of nonverbal cues, reading the mental states of others and, most relevant to our present question, properly understanding social situations in order to know what is appropriate in these situations (Happe and Frith, 2014). Exposure to a nonsocial analogical reasoning task (part of a separate investigation) prior to social content analogical reasoning may have led to better performance than would be observed without any prior analogical reasoning exposure. We were aware of this in devising the study and preferred to optimize conditions for social content analogical reasoning in this first proof-of-concept study, in order to definitively ask whether children with ASD can perform social content analogies at all, under favorable conditions. Our primary question in this study concerned how well children with ASD performed social content analogical reasoning in comparison to TDCs, and this question was not substantively impacted by nonsocial analogical reasoning exposure since this was equivalent between ASD and TDC groups. A conservative conclusion is that children with ASD and TDCs perform social content analogical reasoning similarly *when provided sufficient prior exposure to analogical reasoning beforehand*. An inherent challenge of obtaining a single measure for participants across broad ranges of development and IQ, while ensuring interpretable data among low performers, is that some high-performing participants are likely to perform at ceiling among lower performers. Analyses to account for ceiling effects indicated that removing ceiling performers did not substantially alter our findings. Nonetheless, it is possible that these analyses cannot fully account for ceiling effects, and future research using measures targeted to smaller age and IQ ranges will be important for replicating and extending the current results. The use of still images is likely to be less ecologically valid than videos or live social interactions, which may provide an improved measure of social comprehension in future research.

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