Probability Prediction in Children with ASD

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Abstract

Individuals with Autism Spectrum Disorder (ASD) often struggle with making inductive generalizations. Yet for typically developing children, the capacity to make such generalizations is a hallmark of human learning. This ability requires some understanding of "intuitive statistics" (i.e., the understanding that there is a relationship between samples and populations), which have been previously demonstrated to emerge early on in infancy. We hypothesized that the challenges with inductive generalization among the ASD population may have its roots in weaknesses in probabilistic reasoning. In the current study, we gave children with ASD a probability prediction task adapted from the method used with infants in Teglas et al. (2007), and our results over two experiments with two groups (one from the U.S. and one from Singapore) suggest that compared with typically developing children, children with autism may have difficulties in engaging in probabilistic reasoning.

Keywords: autism; probabilistic reasoning; prediction

Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder that is characterized by impairments in social interaction and communication, as well as the presence of restricted patterns of behaviors and interests (American Psychiatric Association, 2013; Baron-Cohen, 1997). Cognitive research in the field of autism has centered on three traditions when it comes to accounting for ASD (Rajendran & Mitchell, 2007): the theory-of-mind (ToM) hypothesis, which posits that symptoms of autism manifest because of deficits in the ability to impute mental states to oneself and to others (Baron-Cohen, Leslie, & Frith, 1985; Premack & Woodruff, 1978); the executive dysfunction hypothesis, which argues that the symptoms of autism are caused by core difficulties in the planning and execution of complex actions (Hill, 2004; Ozonoff, Pennington, & Rogers, 1991); and the weak central coherence theory, which proposes that individuals with autism favor local processing (i.e., the details) over global processing (i.e., "the big picture") (Happé & Frith, 2006).

A relatively unexplored perspective is that which conceptualizes autism as a disorder of learning (following Pellicano, 2010; Solomon, Smith, Frank, Ly, & Carter, 2011). For instance, a common finding from intervention studies is that individuals with autism often fail to generalize explicitly taught skills across different contexts or to related skills (e.g., Dawson, Mottron, & Gernsbacher, 2005; Hwang & Hughes, 2000; Ivar Lovaas & Smith, 1989; Ozonoff & Miller, 1995). In more recent work, researchers have found that children and adolescents with ASD were less likely to learn from their experiences, and that their generalizations were less consistent when compared to typically developing participants (de Marchena, Eigsti, & Yerys, 2015). Clinicians have also long reported that children with autism often struggle with generalization (Rimland, 1964): for example, after being taught to brush their teeth with a green toothbrush, children with autism may appear to be at a loss when asked to brush their teeth with a red toothbrush later on.

Yet for typically developing children, the capacity to make such generalizations is a hallmark of human learning. Given small amounts of data, human learners readily make inductive inferences, formulating general principles that are extracted from the specific data. Developmental research have repeatedly demonstrated that children are extremely proficient learners, making inductive generalizations with much ease. They learn the meanings of some words with just a single labeled exemplar (Carey & Bartlett, 1978); they generalize non-obvious properties to novel objects after just a short demonstration (Baldwin, Markman, & Melartin, 1993; Gelman & Davidson, 2013; Welder & Graham, 2006), and they learn the physical rules of occlusion with just a single trial (Wang & Baillargeon, 2005).

To make such generalizations proficiently requires some understanding of "intuitive statistics", that is, understanding that a random sample enables one to make predictions about an overall population, and conversely, that a population allows one to make predictions about randomly drawn samples. This type of statistical inference can be found in almost every domain of learning, e.g., physical reasoning, social cognition, word learning, and causal reasoning (Chomsky, 1980; Gelman & Wellman, 1991; Gopnik & Sobel, 2000; Gopnik & Wellman, 2012; Griffiths & Tenenbaum, 2009; Keil, 1981; Kushnir, Xu, & Wellman, 2010; Nisbett, Krantz, Jepson, & Kunda, 1983; Xu & Tenenbaum, 2007), and the ability to make such inferences allows learners to rapidly acquire new knowledge about the world.

Previous research have demonstrated that intuitive statistics emerges very early on in development, enabling children to engage in inductive learning within the first few years of life: 6- to 12-month-old infants are sensitive to differences in probabilities (Denison, Reed, & Xu, 2011;

Téglás, Girotto, Gonzalez, & Bonatti, 2007; Xu & Garcia, 2008) For example, Teglas et al. (2007) showed that in a lottery machine-like setup that consisted of 1 yellow and 3 blue objects bouncing around, infants were more "surprised" to see a yellow object (low probability) exiting the machine, than when a blue object (high probability) did. Furthermore, this early sensitivity has been shown to guide infants and young children in making predictions and in fulfilling their goals and desires (Acredolo, O'Connor, Banks, & Horobin, 1989; Denison & Xu, 2010, 2014; Yost, Siegel, & Andrews, 1962; Zhu & Gigerenzer, 2006).

As such, we hypothesize that the challenges that autistic individuals face with generalization may have their roots in weaknesses in probabilistic reasoning. There is some preliminary evidence for this claim: in a large-scale foraging task where ASD children (8- to 12-year-olds) and matched controls had to search a room for a target among possible search locations embedded into the floor, researchers found that the autistic individuals appeared to be less sensitive to the statistical properties of the search area, taking a much longer time as compared to the matched controls to realize that one side of the room was more likely to contain the target (Pellicano et al., 2011).

In the current study, we directly examined probabilistic reasoning in children with ASD by adapting the method used with infants in Teglas et al. (2007). This method was suitable due to its relatively low task demands and was specifically about probabilistic reasoning. Over two experiments, 6- to 12-year-old children with ASD and matched controls were presented with movies displaying four objects bouncing around a lottery-like machine. The movies were identical to those shown to 12-month-old infants in Teglas et al. (2007). The two groups of children were subsequently asked to predict which object would fall out by choosing between two pictures displaying two possible outcomes.

Experiment 1

Method

Participants The sample consisted of 21 verbally fluent English-speaking 6- to 12-year-old children (18 boys) with ASD. Diagnoses were confirmed through a review of clinical diagnostic reports provided by the parents. The mean age of the sample was 104.6 months (range = 80.6 to 150.6 months). All participants were recruited from Pathlight School, which is an autism-focused school in Singapore that offers mainstream academic curriculum and life-readiness skills. Average Performance IQ was 101.3 (*SD* = 17.3). Two children were tested but excluded for failing the control task.

Materials Seven QuickTime movies simulating four three-dimensional, solid objects bouncing inside a lottery-like machine were presented on a 17-inch screen using the PsyScope software running on a MacBook Pro. These movies were provided by Luca Bonatti from the set of stimuli presented to 12-month-old infants in Teglas et al. (2007). For each movie, two picture cards (8.5 inches x 6 inches) displaying two different possible outcomes were printed in color and laminated. The back of these picture cards had a small Velcro strip with "loops." A separate A4-sized (8.27 inches x 11.69 inches) laminated card was also used, displaying the words "What happened?" above a large empty printed rectangle. At the center of the rectangle was a Velcro strip with "hooks," so a picture card could be attached to this large laminated card.

Procedure Children were tested individually in a quiet room at Pathlight School. They sat about 30 inches from the screen. The children's parents were present in the room, but were seated about 60 inches behind the child's chair. Parents filled out questionnaires throughout the session to reduce the potential for influencing their children's answers.

The procedure consisted of two phases: familiarization and test. Children were shown two familiarization movies, four experimental movies and one control movie. The order of presentation for the four experimental movies was counterbalanced across subjects. Before each movie, a visual attractor always appeared on the screen (with sounds) to orient the child's attention to the center of the screen.

Familiarization Phase In this phase, children watched two familiarization movies in which two types of objects (two of each type, e.g. two blue cubes and two yellow crosses) bounced around the lottery-like container. After approximately 10 seconds, the container was occluded such that the objects could no longer be seen. After another 2 seconds, one of the objects (e.g. a blue cube) fell out of the container accompanied by a "cuckoo" sound. 1 second later, the remaining objects in the container became visible. This procedure was repeated for the next familiarization movie, except that the other type of object (e.g. a yellow cross) fell out of the container this time.

Test Phase In the test phase, children participated in four experimental trials and one control trial. In each experimental trial (Figure 1), three identical objects and one object of a different color and shape (e.g. three blue cubes and one yellow cross) were shown bouncing around the container. After approximately 10 seconds, the container was occluded as in the Familiarization Phase. 2 seconds later, a "cuckoo" sound was made, but the bottom half of the screen was blocked such that it was not possible to see which object had fallen out. The experimenter said, "Something happened, but the screen got blocked!" She then presented two pictures displaying the two possible outcomes (e.g., one of the three identical objects had exited the container vs. the object different in color and shape had exited the container) and said, "Now, I have these two pictures over here." Next, the "What happened?" card was presented and the experiment asked, "Can you show me what happened?" The children were requested to attach one of the picture cards to the large rectangular box. If children failed to respond, the experimenter pointed to the card on the right and said, “If you think this happened, put this card here,” and pointed to the card on the left and said, “If you think this happened, put this card here” in a neutral tone of voice. After children made a clear choice by placing one of the picture cards on to the “What happened?” card, the experimenter proceeded to the next experimental trial. The order of presentation for the four experimental movies was counterbalanced across all participants.

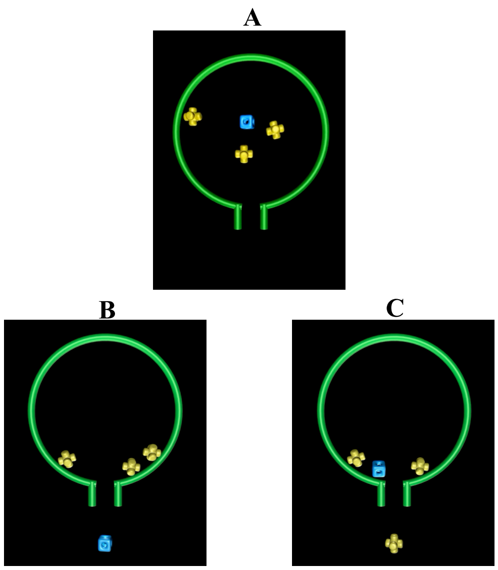

Figure 1: (A) Screenshot from an experimental movie.
(B) & (C) Two pictures displaying two possible outcomes.

After the four experimental trials were completed, children were presented with a control trial (Figure 2). Like the experimental movies, the control movie presented three identical objects and one object different in color and shape bouncing around the container. However, there was now a physical barrier in the middle of the container that confined the three identical objects to the top of the container. As such, it was physically impossible for any of the three identical objects to exit the container. The procedure that followed was exactly the same as that of the experimental trials, and children were asked to choose between two picture cards displaying two different outcomes (e.g. one of the three identical objects had crossed the barrier and exited the container vs. the object different in color and shape had exited the container) as a representation of what had happened.

No feedback was given between any of the test trials. The experimenter only responded with “All right” or “Okay” to all of the children’s choices.

Coding Children’s responses in the test trials (four experimental and one control) were scored for accuracy. As children were asked to predict what had happened, choosing the probable outcome was scored as 1 point. Choosing the improbable/impossible outcome was thus scored as 0 points. A second coder recoded all of the children’s responses, and the level of agreement between the coders was 100%.

Results

An alpha level of 0.05 was used in all statistical analyses. Preliminary analyses found no effects of median age-split (whether the children were younger or older than the median age of the group) and the order of presentation for the four experimental movies. Subsequent analyses were collapsed over these variables.

Overall, we found that the children in the Singapore ASD sample were able to respond correctly in the control trial. 19 out of 21 children responded correctly, and this proportion was significantly different from chance, Exact binomial p (two-tailed) $< .001$. However, children in the final ASD sample consisting of the 19 children who passed the control trial did not perform significantly differently from chance (.50) on the experimental trials, ($M = .47$, $SD = .38$), $t(18) = -.301$, $p = .77$. A conservative binomial test based on the total number of correct trials also showed that children did not perform significantly different from chance, Exact binomial p (two-tailed) $= .77$.

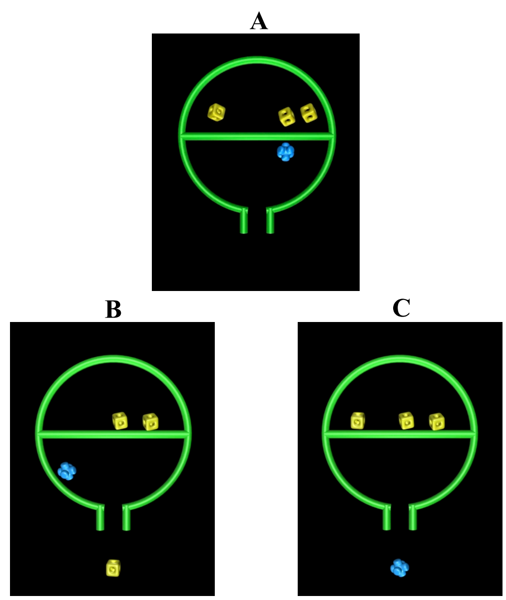

Figure 2: (A) Screenshot from the control movie.
(B) & (C) Two pictures displaying two possible outcomes.

Discussion

The children in the ASD sample in Singapore did not perform reliably better than chance levels in our probability prediction task. This result is striking given that the movies used were adapted from Téglás et al. (2007), in which researchers found strong evidence that 12-month-old typically developing infants have rational expectations about future events based on single-event likelihoods. Furthermore, the low rate of success did not appear to be due to a lack of understanding with regards to the task requirements, since 19 out of 21 of the ASD children (90.5%) answered the control trial correctly. However, it remains a possibility that typically developing children would likewise fail at such a probability prediction task. In other words, while 12-month-old infants may look longer when presented with an improbable event as compared to a probable event, older children may still find it difficult to explicitly make predictions about future events based on their likelihoods. In Experiment 2, we thus collected data from a US sample consisting of both ASD and typically developing children.

Experiment 2

Method

Participants The sample consisted of nine verbally fluent English-speaking 6- to 12-year-old children (8 boys) with ASD and nine typically developing (TD) 6- to 12-year-old children (4 boys), group-matched by chronological age. All participants were recruited from Berkeley, California, and its surrounding communities through advertisements. Diagnoses of the ASD participants were confirmed through a review of clinical diagnostic reports provided by the parents. Participants in the TD group were excluded if they had first-degree relatives with an ASD diagnosis. Age was not found to be significantly different between the two groups (M_{ASD} = 97.07, SD_{ASD} = 18.77; M_{TD} = 98.44, SD_{TD} = 19.93), $t(16)$ = .15, p = .88. The Visual Spatial Index scores, which measure the ability to integrate and synthesize part-whole relationships, to evaluate visual details, and to understand visual spatial relationships, were not significantly different between groups (M_{ASD} = 103.29, SD_{ASD} = 11.45; M_{TD} = 111.33, SD_{TD} = 15.51) as well, $t(14)$ = 1.15, p = .27. This index score was not obtained for two of the children in the ASD sample due to a lack of response to the component subtests.

Materials and Procedure The materials and procedure in Experiment 2 were similar to those of Experiment 1, except for the Familiarization Phase. The Familiarization Phase was modified slightly to increase children's understanding of the task, and the procedure is as follows:

Familiarization Phase In this phase, children watched each of the two familiarization movies twice. During the first familiarization movie, the experimenter commented on the occurring events in such a manner, "Objects bounce around this circle. When you hear this noise [cuckoo noise], one object falls out." The second familiarization movie was then played, and the experimenter commented on the events in the same way. Each of the two familiarization movies was then played once more, without any additional instructions.

Test Phase The test phase in Experiment 2 was identical to that of Experiment 1.

Coding Children's responses in the test trials (four experimental and one control) were scored in the same way as Experiment 1. A second coder recoded all of the children's responses, and the level of agreement between the coders was 100%.

Results

An alpha level of 0.05 was used in all statistical analyses. Preliminary analyses found no effects of median age-split (whether the children were younger or older than the median age of the group) and the order of presentation for the four experimental movies. Subsequent analyses were collapsed over these variables.

Overall, we found that children in both the ASD and TD sample were able to respond correctly in the control trial – all of the children tested made the correct prediction, and this proportion was significantly different from chance, Exact binomial p (two-tailed) < .001. Using children's responses over the four test trials, we then performed a repeated measures logistic regression with group (ASD vs. TD) as the between-subjects variable. Our results indicate that there was a significant difference between the performance of the ASD and TD children, Wald Chi-Square = 7.96, p = .005. A conservative binomial test based on the total number of correct trials also showed that TD children performed significantly better than chance, Exact binomial p (two-tailed) = .029, while ASD children did not, Exact binomial p (two-tailed) = .13.

Discussion

In Experiment 2, we found a significant difference between the performance of the ASD and TD children: Children in the ASD sample in Berkeley did not perform reliably better than chance levels in our probability prediction task, which replicates our findings in Experiment 1. In contrast, typically developing children were successful at this task and were able to make predictions about future events based on their likelihoods. This difference found between the two groups did not appear to be due to a difference in the children's ability to understand the task requirements, as all of the participants were able to respond to the control trial correctly.

General Discussion

The present study examined whether children with Autism Spectrum Disorder (ASD) show weaknesses in probabilistic reasoning. Using a probability prediction task adapted from a method used with 12-month-old infants (Teglas et al., 2007), we found across two different samples that high-functioning, verbally fluent children with ASD struggled with making predictions about future events based on their single-event likelihoods. In contrast, our comparison group of typically developing children were successful in making such predictions, consistent with results obtained from previous studies with infants and young children (Acredolo et al., 1989; Denison & Xu, 2010, 2014; Yost et al., 1962;

Zhu & Gigerenzer, 2006). The current findings are striking, considering that the two groups of children in Experiment 2 did not differ in their Visual Spatial Index scores, which are particularly relevant for processing the stimuli presented in our task.

May our results be better accounted for by the three dominant cognitive theories for ASD? While more research would be necessary to carefully tease these accounts apart, we have reason to believe that the current cognitive theories do not necessarily do so. According to the theory-of-mind hypothesis, the core deficit of autism is a failure/delay in taking into account others' mental states. Given that our task does not ostensibly require participants to impute the mental state of others, it is unlikely that the difference found in probabilistic reasoning between the ASD and TD groups would be related to any previously established differences in ToM. With regards to the executive dysfunction hypothesis, the high rate at which the ASD children were passing the control task suggests that they had an ability to sustain attention to the presented movies in the current study. It is possible that this group of children appeared to respond correctly on the control trial due to difficulties in inhibiting the prepotent response of selecting the dissimilar object exiting as the predicted outcome (i.e., choosing the picture with one blue object outside of the container, rather than the picture with one of the three identical yellow objects outside of the container). However, if this alternative explanation were to be true, then the ASD children should have performed significantly worse than chance on the experimental trials because of an equivalent tendency to select the low-probability outcomes. Finally, the weak central coherence theory posits that autism is characterized by a weak drive towards obtaining global coherence, such that individuals with autism are predisposed to process information in a detail-focused, piecemeal way. Again, it is unclear how such a theory would account for the different success rate that children with ASD show on the experimental trials vs. the control trials; how would attending to the details of the movies in a segmented manner lead children to pass the control but not the experimental trials?

Therefore, our results suggest that there may be early differences in probabilistic reasoning between children with autism and typically developing children. This weakness in "intuitive statistics" may result in impairments in making inductive generalizations. Given the centrality of inductive learning in almost every domain of knowledge, such early difficulties may lead to a cascade of negative consequences in development. Work is ongoing in our lab to examine more closely the deficit in probability prediction using other related tasks, and whether the deficits in probabilistic reasoning may be directly linked to deficits in the ability to make inductive generalizations.

Finally, given that probabilistic reasoning emerges early on in infancy (Denison et al., 2011; Téglás et al., 2007; Xu & Garcia, 2008), the current results showing possible weaknesses in such early intuitions may inform early diagnosis. In addition, the current work examines autism through the lens of learning, which may allow its findings to be more amendable to the design of interventions, an aspect that is especially important to stakeholders of the ASD community. As such, we believe that the current work is a first step towards opening up new grounds in the study of autism.

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