J Autism Dev Disord (2012) 42:1694–1704
DOI 10.1007/s10803-011-1411-x

ORIGINAL PAPER

Category Formation in Autism: Can Individuals with Autism Form Categories and Prototypes of Dot Patterns?

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Published online: 3 December 2011
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Abstract There is a growing amount of evidence suggesting that individuals with autism have difficulty with categorization. One basic cognitive ability that may underlie this difficulty is the ability to abstract a prototype. The current study examined prototype and category formation with dot patterns in high-functioning adults with autism and matched controls. Individuals with autism were found to have difficulty forming prototypes and categories of dot patterns. The eye-tracking data did not reveal any between group differences in attention to the dot patterns. However, relationships between performance and intelligence in the autism group suggest possible processing differences between the groups. Results are consistent with previous studies that have found deficits in prototype formation and extend these deficits to dot patterns.

Keywords Categorization · Prototype · Autism · Cognition · Eye-tracking · Implicit

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Introduction

Categorization is critically important, because it reduces demands on memory and allows individuals to focus on important aspects of objects while ignoring irrelevant details. Categorization helps children to learn language, and within the first year of life, it is evident that infants begin to form categories (e.g., Lewis and Strauss 1986; Oakes et al. 2010). There is also a growing amount of evidence suggesting that individuals with autism have difficulty with some aspects of object categorization and engage in different categorization processes than do typically developing individuals (e.g., Gastgeb et al. 2006; Klinger and Dawson 1995).

While individuals with autism can successfully categorize on the basis of simple definitive features, they have difficulty categorizing when the categories are based on more complex and less perceptually apparent features (e.g., Klinger and Dawson 1995), as is true of most natural categories (e.g., Rosch and Lloyd 1978). Thus, with respect to natural categories such as couches and chairs, children and adults with autism do not demonstrate any difficulties when categorizing typical or more prototypic category members that have clear, simple features (e.g., short vs. long length for chairs vs. couches). However, they demonstrate deficits when the category members are atypical or poor category members and when the categorization decisions rely on comparing the exemplars to central or prototypic representations of the category (Gastgeb et al. 2006; Newell et al. 2010.). When individuals with autism do form categories, they appear to do so in a way that is different from typically developing individuals. For example, individuals with autism do not group words into categories to aid in memorization (e.g., Minshew et al. 1992). They also process information in a rule-based manner, leading to difficulty when tasks require that concepts or categories be abstracted from complex information (e.g., Minshew et al. 2002). Finally, individuals with autism process features that are common between objects poorly while processing features that are unique to an object well (Plaisted et al. 1998).

One basic cognitive ability that is necessary for categorization and may underlie the categorization differences and deficits in autism is the ability to abstract a prototype. A prototype is an average representation of past information that depicts the average of the variations within a given category that is stored in memory. The ability to form a prototype is a critical skill for category learning, because it decreases memory load and allows individuals to store an average representation of experienced items rather than needing to store every item in memory. It is also an example of implicit learning in that it is an automatic process; people form prototypes without any outside instruction, effort, or awareness. Studies have demonstrated that within the first year, typically-developing infants can form prototypes of faces (e.g., Rubenstein et al. 1999; Strauss 1979), objects (e.g., Younger 1990) and dot patterns (e.g., Younger and Gotlieb 1988).

Evidence of prototype formation in children and adults comes from studies of the prototype effect—the tendency to falsely remember a prototype as previously seen despite never actually seeing it. In a classic study by Posner and Keele (1968), adults trained on dot patterns varying in distortion levels from a prototype tended to falsely remember the unseen prototype and considered it to be as familiar as previously seen dot patterns. This effect has been replicated using a wide range of stimuli, including dots (e.g., Kéri et al. 2001), abstract forms (e.g., Homa et al. 1993), and faces (e.g., Gastgeb et al. 2011). Researchers have also found a relationship between the similarity of a pattern/object to the prototype of a certain category and the likelihood of it being recognized as a member of that category, with stimuli of high similarity (or small amounts of distortion from the prototype in the case of dots) resulting in greater recognition than low similarity (or high amounts of distortion from the prototype in the case of dots) (e.g., Knowlton and Squire 1993).

Although there has been relatively little research on prototype formation in autism, a few studies suggest that individuals with autism are poor at abstracting prototypes and do not exhibit the prototype effect. Klinger and Dawson (2001) compared low-functioning children with autism, children with Down's syndrome, and typically developing children's abilities to use rule-based versus prototype category learning. They found that the children with autism (and Down's syndrome) did not abstract a prototype of simple animal-like categories during category learning. This finding has recently been replicated with high-functioning children and adults with autism, indicating that the inability to form prototypes in the Klinger and Dawson (2001) study probably cannot be explained by mental retardation or general level of cognitive functioning (Klinger et al. 2006). More recently, Gastgeb et al. (2009) and Gastgeb et al. (2011) extended these deficits to line drawings of faces and subtly varying natural faces and found that high-functioning individuals with autism did not form a prototype of faces in either study. Gastgeb et al. (2011) also collected eye-tracking data and determined that the lack of prototype formation could not be accounted for by a lack of attention to faces or relevant features, differential attention to features, or different attentional patterns to faces.

In contrast, Molesworth et al. (2005, 2008) did not find evidence of a lack of prototype formation in high-functioning children with autism spectrum disorder; however, their results may not reflect intact prototype formation abilities. Aspects of the study design (e.g., the use of obvious features, lacking subtle variation between feature values, the use of the exact same feature values in the familiarization and test phase) may have permitted individuals with autism to show a prototype effect due to memorization of specific features or by focusing on the variations in one feature rather than forming a prototype.

While not a direct study of prototype formation, Bott et al. (2006) investigated low-level category formation ability in high-functioning adults with autism. During the training phase, participants were shown rectangles varying in height and width from two different categories. They were instructed to learn which rectangles belonged to each category and were provided feedback until they successfully learned the two categories. During the test phase, participants were again presented with the rectangles from the learned categories in addition to novel rectangles from these categories, but without feedback. It was found that even though the individuals with autism performed similarly to the control individuals on the test trials, it took the individuals with autism significantly longer to learn the categories.

Only one study to date has examined the ability of individuals with autism to form a prototype of dot patterns. Vladusich et al. (2010) studied prototypical category learning in high-functioning adolescent and adult males with autism. During the training phase, participants were shown "creatures" from two different dot pattern categories that were of a medium amount of distortion from the category prototypes. They were instructed to learn which type of "creature" belonged to each category and were provided feedback until they successfully learned the two categories. During the test phase, participants were shown dot patterns of a medium amount distortion that they had preciously seen (MF) in addition to novel dot patterns of a low (LN), medium (MN), and high (HN) amount of distortion from the category prototypes. Again, they were asked to categorize the dot patterns, but now without feedback. Similar to Bott et al. (2006), it was found that while the individuals with autism did show an intact prototype effect (i.e., greater accuracy for low distortion novel dot patterns than medium distortion previously seen dot patterns), they required significantly more training trials to learn the categories in the training phase and had significantly lower accuracy during the training and test trials.

Interestingly, for the individuals with autism, there was also a significant correlation between nonverbal IQ and accuracy during the test phase. Therefore, it is possible that successful performance on this task was not due to intact prototype formation ability, but rather alternative strategies that were successfully developed by individuals with higher IQs. Since the authors used an explicit learning design in which participants were told that they were to learn the categories, and the task involved two contrasting categories, it is possible that more intelligent individuals with autism developed a strategy that allowed them to learn subsets of the dot patterns that were maximally different between the categories (or some other alternative strategy) as opposed to actually abstracting prototypes of the two categories during the training phase. As stated earlier, in most classic studies of prototype formation, the abstraction of a prototype is done as an implicit, automatic process. Therefore, being provided explicit instructions to form categories may make the task more explicit in nature and afford different kind of learning strategies than are present in paradigms that present just a single category and where specific training is not given (e.g., Kéri et al. 2001).

The current study aimed to replicate the findings of previous prototype studies while also examining implicit category formation using dot patterns in a group of high-functioning adults with autism. Using dot patterns which are non-social and involve no prior knowledge or experience allows one to study the pure process of prototype and category formation without the confounds of social difficulty or experience. The only previous study of dot pattern prototype formation in autism (Vladusich et al. 2010) used contrasting categories and an explicit learning design that may have led to alternative strategy development in the individuals with autism. In order to minimize these types of strategies and to more closely replicate real-life categorization, the current study used only one category and an implicit learning design in which the participants were not told that they were learning a category of dot patterns. Participants were instead shown dot patterns that were a high amount of distortion from a prototype and were then tested on their ability to correctly categorize dot patterns that were the prototype, low distortions of the prototype, new high distortions of the prototype, and non-category dot patterns (patterns from another dot pattern category).

Participants' eye movements were also recorded in order to gather vital information about which areas of the dot patterns individuals with autism and control individuals looked at when viewing the familiarization stimuli (learning). If there are between group differences in prototype/category formation ability, one potential explanation for these differences could be that the groups differed in the way in which they distributed their attention to the dot patterns. For example, if the autism group spent less time looking at the dot patterns and more time looking at the background, they would be less likely to form a prototype during the familiarization phase. Similarly, if the autism group looked at fewer dots than the control group, they would be less likely to form a prototype. The current study also explored the distribution of performance in both groups and the relationship between performance and measures of intelligence. Therefore, unlike previous prototype formation studies, the current study addressed both *if* individuals with autism have deficits in forming prototypes/categories in addition to *why* they may have these deficits.

Methods

Participants

Participants consisted of 20 high-functioning, adult males with autism and 19 healthy, control adult males recruited by the Autism Center for Excellence (ACE) at the University of Pittsburgh. It should be noted that the original data-set included 20 control adults, but one individual was excluded, because he was an outlier (i.e., all of his means from the dot pattern task were more than two standard deviations different from the rest of the control sample). Control participants were matched with participants in the autism group on age, full scale IQ (FSIQ), verbal IQ (VIQ), and performance IQ (PIQ). All participants had IQ scores greater than 80 as determined by the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). Table 1 summarizes the participants' demographic characteristics. No significant differences were found between the two groups on age, FSIQ, VIQ, or PIQ (age t (37) = −1.45, p = .16; FSIQ t (37) = −1.55, p = .13; VIQ t (37) = −1.66, p = .11; PIQ t (37) = −.37, p = .71).

Individuals with autism were recruited through informational visits to service providers throughout the state of Pennsylvania and the surrounding states, fliers at autism meetings, advertisements in autism newsletters, and posters. All participants with autism met criteria for autism on the Autism Diagnostic Observation Schedule (Lord et al. 1989) and the Autism Diagnostic Interview-Revised (Lord et al. 1994), which was verified by expert clinical opinion. Participants with Asperger's disorder or Pervasive

Table 1 Participants' diagnostic and demographic characteristics

Autism group				Control group			
Age	VIQ	PIQ	FSIQ	Age	VIQ	PIQ	FSIQ
17*	99	110	106	18	116	109	115
18	99	103	101	18	117	118	119
18	100	115	108	21	111	106	109
18*	105	112	109	21	110	114	114
19	101	110	107	22	109	108	110
19	119	111	117	22*	122	109	118
19	119	128	128	23	113	100	108
20	103	93	98	23	108	112	112
21	107	112	111	24	113	103	109
21	118	104	112	24	119	112	118
21	107	119	114	26	100	93	97
22	117	119	120	27*	114	120	119
23*	121	83	101	29	116	119	119
23*	127	88	107	30	115	116	117
24	89	111	100	31*	117	119	120
24	115	105	111	32	114	119	118
29*	108	131	121	32*	113	125	121
36	108	121	116	37*	109	119	116
37	96	125	109	42	106	106	107
M							
23.40	108.55	110.70	110.55	26.42	112.74	111.95	114.00
SD							
6.64	9.83	12.41	7.67	6.38	5.05	8.09	6.08

Age years, *VIQ* Verbal IQ, *PIQ* Performance IQ, *FSIQ* Full Scale IQ

* Excluded from Eye-tracking

Developmental Disorder were excluded. Potential participants with autism were excluded if found to have a history of seizures or evidence of an associated neurologic, genetic, infectious, or metabolic disorder. Exclusions were based on physical examination, neurologic history and examination, and chromosomal analysis.

Control participants were volunteers recruited from the community through advertisements. Potential control participants were screened by completing family and personal history questionnaires of medical, neurological, and psychiatric disorders (Adult Symptom Inventory-4, Gadow et al. 1999; Family History Screen, Weissman et al. 2000). Exclusion criteria included a personal history of neurological or psychiatric disorders, learning disability, brain injury prior to or after birth; loss of consciousness; poor school attendance; a medical disorder with implications for the central nervous system or requiring regular medication usage; a family history in first-degree relatives of learning disability, mood disorder, or anxiety disorder; and a family history of autism in first-, second-, or third-degree relatives.

Apparatus

Testing occurred in a quiet, dark laboratory room that simulated a small movie theater and provided maximum comfort. Each participant was seated in a modified desk chair in front of a large rear projection movie screen (69 × 91 cm). The testing area was surrounded by black curtains to reduce distractions. A stand-alone eye-tracker that required no attachments to the participant was positioned on a table in front of the participant. Stimuli were rear projected onto the screen using Tobii Studio software, and eye movements were recorded by a Tobii X120 stand-alone eye tracker at a sampling rate of 60 Hz, accuracy of .5% of visual angle, spatial resolution of .2%, and drift of .3%. The eye-tracker sat 81 cm in front of the projection screen, and the participants were positioned approximately 162 cm from the screen. A Dell Dimension 9200 displayed experimental stimuli and recorded eye-movement and behavioral accuracy data. Responses were recorded by keypad response using a two button Ergodex DX1 input system response pad. Eye-tracking and behavioral data were processed using Tobii Studio software, Version 2.6.

Stimuli

Stimuli were constructed following procedures used by Kéri et al. (2001). All stimuli were created in Excel using a 50 × 50 cell matrix. The dot prototype was constructed by placing nine filled dots into the central 30 × 30 cell area in a pattern very similar to that used as the prototype in Kéri et al. (2001). Each within category stimulus was constructed by systematically distorting the placement of each dot according to a subset of the statistical rules and procedures that were used to create distortions of prototype stimuli in a set of studies by Posner et al. (1967). These statistical rules and procedures have been used by many researchers studying dot prototype formation in typically developing and clinical populations (e.g., Kéri et al. 2001; Knowlton and Squire 1993; Zaki and Nosofsky 2007). Within category stimuli consisted of 20 low distortions of the prototype and 60 high distortions of the prototype. The low distortions were formed using the statistical rules that correspond to Posner et al. (1967) distortion level three and the high distortions were formed using the statistical rules that correspond to distortion level six. Table 2 shows the statistical rules for low and high distortions.

The stimuli were created using the following procedure. A template of 400 cells was constructed with the center cell labeled zero, the surrounding eight cells labeled 1–8, the next ring of cells numbered 9–24, and the remaining cells numbered 25–399 in a clockwise spiral fashion. Five areas, as seen in Table 2, were assigned consisting of Area 1 (the central cell, cell zero), Area 2 (cells 1–8), Area 3 (cells 9–24), Area 4 (cells 25–99), and Area 5 (cells 100–399). Each stimulus began as the prototype. The template was placed over the first dot and a statistical calculator was used to calculate which cell of the template the dot would move to according to the corresponding probabilities for that stimulus. The dot was then moved to the cell on the 50×50 grid that corresponded to the cell on the template that was chosen. This was repeated for all nine dots for that stimulus. Thus, for the low distortion stimuli, each dot had a .59 probability of staying in place (Area 1), .20 of moving to Area 2, .16 to Area 3, .03 to Area 4, and .02 to Area 5. As a result, the low distortion stimuli were very similar to the prototype stimulus in form. The dots in the high distortion stimuli had a zero probability of staying in the same position, and therefore all high distortion stimuli were guaranteed to consist of a pattern of dots that was less similar to the prototype than the low distortions but was still within the same category of dot patterns as the prototype, low distortions, and other high distortions.

Table 2 Probabilities of a dot moving to each area for low and high levels of distortion

	Area				
Level of distortion	1	2	3	4	5
Low	.59	.20	.16	.03	.02
High	.20	.30	.40	.05	.05

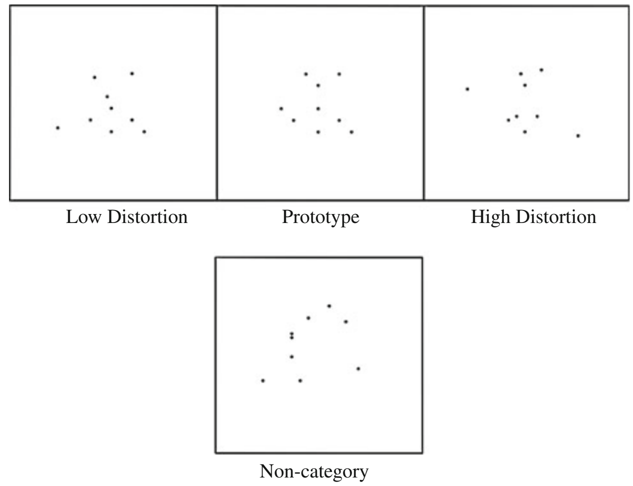

Fig. 1 Examples of experimental stimuli

In addition to the within category dot stimuli, 40 non-category dot patterns were created by making 40 high distortions of a completely different dot pattern using the same statistical principles as those that were used to make the within category dot patterns. In total, the stimuli consisted of a prototype, 20 low distortions, 60 high distortions, and 40 non-category stimuli (high distortions of a different dot pattern). Figure 1 depicts an example of each of these types of stimuli.

All stimuli were created in Excel following the procedure outlined above. They were then converted into jpeg image files using SnagIt, a screen capture program. Finally, the stimuli were resized to ensure that they were all the same size and quality. When projected, each dot was one-centimeter in diameter and the entire stimulus subtended a visual angle of 32×26 degrees.

Procedure

Participants were told that they would be viewing a series of dot patterns on the screen in front of them. Participants were familiarized with the eye-tracking equipment and seated in front of the eye-tracker and projection screen. During the calibration, participants were required to look at the calibration points on the screen in front of them. The calibration procedure was repeated until it was successful. After the calibration, participants were instructed to look at the dot patterns on the screen but were not given any other instructions.

The procedure was identical to that used by Kéri et al. (2001). During the familiarization trials, participants were presented with 40 high distortions of the prototype. These stimuli were presented in a random order and were on the screen for 5 s with an interstimulus interval of one second in which a grayscale striped gradient was presented in order to decrease the amount of afterimage that was created by the previously seen dot stimulus. Following the familiarization phase, there was a 5 min break in which participants were permitted to stand up and move around but otherwise did not engage in any other tasks. After this delay period, participants were given a response pad with two buttons labeled "yes" and "no". Participants were told that they were going to see more dot patterns and they needed to decide if they dot patterns were members of the previously seen category or not by pressing "yes" for category members, and "no" for non-category members. During the test trials, participants were presented with four instances of the prototype, 20 low distortions of the prototype, 20 new high distortions of the prototype, and 40 non-category dot patterns in randomized order. Each stimulus was presented until the participant responded by pressing a button on the response pad. The left–right orientation of the labels was counterbalanced across participant. During the entire procedure, the participants' eye movements and responses were recorded by Tobii Studio.

Eye-tracking Data Preparation (Areas of Interest—AOIs)

All familiarization stimuli were partitioned into areas of interest (AOIs) corresponding to each dot, the figure, and the whole stimulus. Each Dot AOI was drawn as circle with a 15 mm diameter. The AOI was placed so that the dot was in the exact center of the circle. If two dots in a stimulus were in positions that would result in the Dot AOIs overlapping, one Dot AOI was drawn that included both dots as part of that AOI. When this occurred, the AOI was placed so that each dot was equally included in the AOI (see Fig. 2). The Figure AOI was drawn as a box that extended vertically and horizontally to include all nine dots. The Stimulus AOI was drawn as a box that included the entire stimulus (background and dots). Figure 2 shows an example of all AOIs.

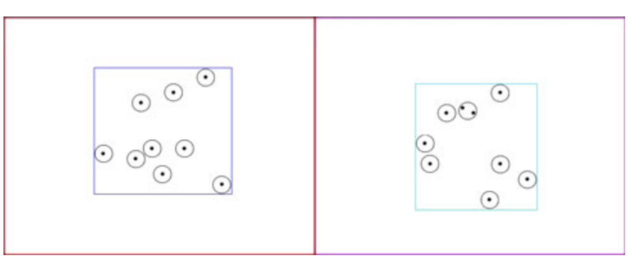

Fig. 2 Example of the areas of interest (AOIs) used for eye-tracking

Results

Percent Endorsed Data

Between Group Analyses

The primary dependent measure of interest was percent endorsed, or the percentage of instances in which the dot patterns were classified as members of the previously seen category (learned category). One potential problem with analyzing the percent endorsed data is that participants who had a bias towards pressing "Yes" would have high scores even if they did not abstract the prototype and category of the dot patterns during the familiarization phase. Therefore, in order to control for response bias, d-prime (d') scores were calculated for the prototype, low distortion, and high distortion stimuli.

Before calculating d', the number of Hits, Misses, False Alarms, and Correct Rejections had to be calculated. Hits (H) were defined as responses in which the participant correctly endorsed a prototype, low distortion, or high distortion dot pattern as a member of the previously seen category. Misses (M) were defined as responses in which the participant incorrectly rejected a prototype, low distortion, or high distortion dot pattern as a member of the previously seen category. False Alarms (FA) were defined as responses in which the participant incorrectly endorsed a non-category dot pattern as a member of the previously seen category. Correct Rejections (CR) were defined as responses in which the participant correctly rejected a non-category dot pattern as a member of the previously seen category. d' was calculated separately for prototype, low distortion, and high distortion dot patterns using the following formula:

$$d' = z(\#\,H/(\#\,H + \#\,M)) - z(\#\,FA/(\#\,FA + \#\,CR))$$

The d' results are presented in Fig. 3. A 2-way ANOVA was conducted, with group (autism vs. control) as the between-subjects factor and distortion level (prototype vs. low vs. high) as the within-subjects factor. Results indicated a significant main effect of distortion, $F\ (2, 74) = 82.85$, $p < .001$. Post hoc comparisons (Holm-Bonferroni) resulted in significant differences between all distortion levels with d' being highest for the prototypes ($M = 2.82$), second highest for the low distortions ($M = .90$), and the lowest for the high distortions ($M = .61$). All comparisons were significant at the $p < .001$ level. Results also evidenced a significant main effect of group, $F\ (1, 37) = 10.99$, $p < .01$. In general, the control group ($M = 1.85$) endorsed significantly more prototypes, low distortions, and high distortions as category members and excluded more non-category members from the learned category than the autism group ($M = 1.06$).

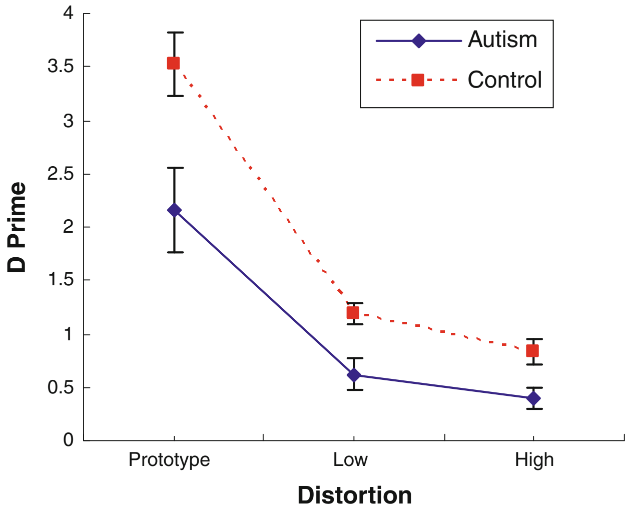

Fig. 3 D-prime by distortion level

The interaction of distortion and group was also significant, F (2, 74) = 3.61, $p < .05$. Post hoc paired comparisons (Holm-Bonferroni) conducted separately for the autism and control groups showed that like the combined data, the control group had the highest d′ scores for the prototypes ($M = 3.53$), second highest for the low distortions ($M = 1.19$), and the lowest for the high distortions ($M = .83$). All comparisons were significant at the $p < .001$ level. The autism group showed a similar pattern with d′ being the highest for the prototypes ($M = 2.16$), second highest for the low distortions ($M = .62$), and the lowest for the high distortions ($M = .40$). All comparisons were significant at the $p < .001$ level except the comparison between the high and low distortions, which was significant at the $p < .05$ level. This suggests that there was a stronger pattern of prototype > low > percent endorsement for the control group than the autism group. This was especially true for the comparison between the low and high distortions.

Independent samples t-tests were performed on all distortion levels to determine whether there were any group differences in the d′ data. The control group ($M = 3.53$ and $M = 1.19$ and $M = .83$) had higher d′ scores for the prototypes, low distortions, and high distortions than the autism group ($M = 2.16$ and $M = .62$ and $M = .40$) (t (37) = -2.72, $p < .05$ for prototypes, t (37) = −3.11, $p < .01$ for low distortions, and t (37) = −2.65, $p < .05$ for high distortions). Thus, once response bias was controlled for, the control group showed significantly better performance for all distortions than the autism group.

In addition to these overall group differences, analyses were conducted to address potential differences in the variability or distribution of performance on the prototype stimuli between the two groups. While 84% of participants in the control group correctly endorsed the prototype stimuli in four out of four trials, only 50% of the autism group performed at this level. In order to analyze the distribution of performance across groups, the groups were divided into subgroups of "good performers" and "poor performers." Good performers were defined as participants who performed as well as the majority of the control group and correctly endorsed the prototype as a category member in four out of four trials, while poor performers were defined as those who correctly endorsed the prototype as a category member in three or fewer trials. A Chi-square analysis comparing the distribution of good performers ($n = 10$ in the autism group, $n = 16$ in the control group) and poor performers ($n = 10$ in the autism group, $n = 4$ in the control group) revealed a significant association between diagnosis and prototype formation, $\chi^2(1) = 5.13$, $p < .05$. Based on the odds ratio, individuals in the control group were 5.33 times more likely to correctly categorize the prototype in all trials than were individuals in the autism group.

To determine whether performance was related to measures of intelligence in either group, correlations between measures of prototype and category formation (d′) and measures of intelligence (VIQ, PIQ, and FSIQ) were calculated separately for the autism and control groups (see Table 3). In the autism group, d′ for the prototype dot patterns was positively related to PIQ ($r = .63$, $p < .01$) and FSIQ ($r = .63$, $p < .01$). Even though it did not reach significance, there was a positive relationship between PIQ and category formation for both the low distortions ($r = .37$, $p = .10$) and the high distortions ($r = .37$, $p = .10$). There was also a non-significant positive relationship between FSIQ and category formation for the high distortions ($r = .42$, $p = .07$). None of the correlations reached significance for the control group.

Table 3 Correlations between d′ and measures of intelligence

	Autism	Control
Prototype d′		
VIQ	.08	−.07
PIQ	.63*	−.33
FSIQ	.63*	−.24
Low distortion d′		
VIQ	−.01	−.25
PIQ	.37	−14
FSIQ	.34	−.20
High distortion d′		
VIQ	.08	−.35
PIQ	.37	−16
FSIQ	.42	−.26

*$p < .01$

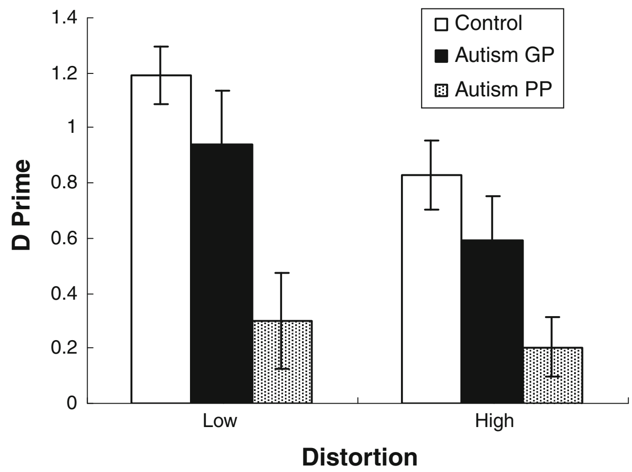

Fig. 4 D-prime by distortion level for good performers (GP) and poor performers (PP) with the control group as a comparison

Within Autism Group Analyses

An interesting question is whether individuals with autism who were able to form a prototype of the dot patterns also formed more well-defined categories of dot patterns. In other words, did the good performers endorse more high and low distortions as category members and exclude more non-category stimuli as members of the learned category. To address this question, d′ scores for participants with autism who were good performers were compared to those of poor performers (see Fig. 4). The control group data are also included in the figure as a comparison. Independent samples t-tests indicated that the good performers ($M = .94$) endorsed significantly more low distortions as category members than the poor performers ($M = .30$), $t\ (18) = 2.43$, $p < .05$. The results for the high distortions approached significance with good performers ($M = .59$) endorsing significantly more high distortions as category members than poor performers ($M = .21$), $t\ (18) = 1.98$, $p = .06$. Independent samples t-tests also showed that even though their scores were somewhat lower, the data for the good performers were not significantly different from the control data for any level of distortion.

Eye-Tracking Results

Of the 20 individuals with autism and the 19 control individuals, 15 individuals with autism and 14 control individuals were included in eye-tracking analyses. Five participants in each group were excluded due to poor eye-tracking data (e.g., poor calibration or lack of accurate eye-tracking). As with the full participant set, no significant differences were found between the two groups on age, FSIQ, VIQ, or PIQ. There were also no significant differences between the participants who were included in the eye-tracking analyses and those that were excluded on age, FSIQ, VIQ, PIQ, or any d′ measure.

Between Group Analyses

The first question is whether the autism and the control groups differed in the proportion of time that they spent looking at the dot pattern versus the whole stimulus (% Figure). The % Figure was calculated by dividing the total amount of time that the participants spent looking at the Figure AOI (across all familiarization trials) by the total amount of time that they spent looking at the Stimulus AOI (across all familiarization trials) and multiplying the result by 100. An independent samples t-test determined that the autism ($M = 98.71\%$) and control group ($M = 99.58\%$) did not differ in the percentage of time that they spent looking at the dot patterns, $t = -1.57$, $p = .13$.

The second question is whether the autism and control groups differed in the number of dots that were fixated upon during the familiarization trials (% Dots). The % Dots was used as the dependent measure rather than the number of dots, because some dot patterns had fewer than nine dot AOIs due to the location of the dots in the dot pattern. An independent samples t-test determined that the autism ($M = 28.99\%$) and control group ($M = 26.70\%$) did not differ in the percentage of dots that they fixated upon during the familiarization trials, $t = .43$, $p = .67$. In fact, neither group directly looked at more than two to three out of nine dots on average.

Within Group Analyses

Also of interest is whether there were any eye-tracking differences between the good and poor performers in the autism group. For % Figure, an independent samples t-test determined that the good ($M = 98.6\%$) and poor performers ($M = 98.83\%$) did not differ in the percentage of time that they spent looking at the dot patterns, $t = -.01$, $p = .99$. For % Dots, an independent samples t-test determined that the good ($M = 28.95\%$) and poor performers ($M = 29.04\%$) did not differ in the percentage of dots that they fixated upon during the familiarization trials, $t = -21$, $p = .84$.

Discussion

One objective of the current study was to investigate whether individuals with autism, in contrast to typically developing individuals, experience difficulty abstracting prototypes and categories of dot patterns. Results indicated that similar to previous research, all participants showed a pattern of results where d′ was highest for the prototypes, second highest for the low distortions, and lowest for the high distortions. However, even though the individuals with autism showed this pattern, their categorization performance was significantly poorer for the prototypes and all levels of distortion. In fact, the control group endorsed significantly more prototypes, low distortions, and high distortions as category members and excluded more non-category members from the learned category than the individuals with autism. In addition, while 84% of the participants in the control group correctly categorized the prototype in all trials (good performers), only 50% of the individuals with autism performed at this level.

Taken together, the results suggest that the control group formed a more well-defined category and prototype of dot patterns than the individuals with autism by including more category members into the learned category and excluding more non-category patterns from the learned category. In contrast, the individuals with autism evidenced "fuzzier boundaries" and included fewer category members and more non-category patterns into the learned category. Therefore, even though the individuals with autism showed the same pattern of results as the control group, they evidenced difficulty with both forming a prototype and category of dot patterns. These results parallel previous findings in gender and object categorization indicating that individuals with autism have "fuzzy category boundaries" and have difficulty categorizing less typical members of natural objects and gender categories (e.g., Gastgeb et al. 2006; Newell et al. 2010) and extended these results to artificial categories such as dot patterns.

In addition to understanding whether individuals with autism have a deficit in prototype and category formation, it is important to discuss *why* the individuals with autism as a group had difficulty with prototype formation, and why some appeared to perform well. Difficulties in prototype formation may be related to differences in the way in which individuals with autism cognitively process information. Two theories that address potential differences in perceptual processing are weak central coherence (Frith and Happé 1994) and enhanced perceptual functioning (Mottron et al. 2006). According to these theories, individuals with autism prefer parts over wholes, have a local processing bias, and focus on details. It is also possible that individuals with autism may not have paid sufficient attention or may have attended differently to the dot patterns, resulting in difficulty forming a prototype and category. However, the eye-tracking data suggest that neither explanation is sufficient; the individuals with autism did not differ from the control individuals in the percentage of time they spent looking at the dot patterns in general or the number of dots that they attended to while learning the category. Therefore, it is more likely that the individuals with autism experienced difficulty with the implicit, automatic processes that are required for prototype and category formation.

Further support for this idea arises from the relationships that were found between performance and measures of intelligence in the autism group but not the control group. Performance was significantly positively correlated with PIQ and FSIQ for the prototype stimuli. While the correlations did not reach significance, performance was also positively related to PIQ and FSIQ for the low and high distortions. These results suggest that while the control participants performed as expected and appeared to form a prototype and category using implicit processes, the individuals with autism who performed well may have used their increased nonverbal intelligence skills to explicitly find alternative methods or strategies to perform well on the task.

In general, the results of the current study are consistent with past research that has found a deficit in prototype formation in individuals with autism (Gastgeb et al. 2009, 2011; Klinger and Dawson 2001; Klinger et al. 2006). They also parallel the findings of Vladusich et al. (2010) in that both studies found that while the prototype effect was intact, the individuals with autism had lower levels of accuracy than the control group for all levels of distortion. Both the current study and Vladusich et al. (2010) also found a significant positive relationship between successful performance on the task and PIQ. Taken together, the results suggest that individuals with autism who perform well on prototype and category formation tasks may not do so using implicit processes, but rather may find alternative ways to succeed that allow them to perform somewhat well on the task, but not as well as control individuals who do appear to be using implicit, automatic strategies to succeed. The variability that is present in task performance in individuals with autism, and the possibility of alternative strategies for success may explain the mixed findings in the prototype formation and categorization literature. Therefore, future research on prototype formation and categorization should continue to examine individual differences in performance and possible alternative strategies for success in order to truly understand the nature of any deficits and/or differences in individuals with autism.

While the current results are inconsistent with prior research by Molesworth et al. (2005, 2008), methodological differences between the current study and prior studies are likely responsible for the divergent findings. The current study more closely replicated real life prototype formation, an implicit and automatic process that is present from early infancy, possibly even from birth. Most importantly, the current study used an implicit learning design, a design that is critically important to consider for future research in autism. It has been suggested that individuals with autism have unique impairments with respect to implicit cognitive processes (see, Eigsti and Mayo 2011; Newell et al. 2010). When a person is instructed to form categories, the task is no longer an implicit and automatic task but is transformed into an explicit task in which there can be rules or strategies that are used to succeed. Since individuals with autism can successfully categorize on the basis of simple definitive features and when provided with a rule or strategy (Gastgeb et al. 2006; Klinger and Dawson 1995), and performance on prototype tasks has been found to be related to PIQ in these individuals (Vladusich et al. 2010), use of an implicit learning design is especially important for research on prototype and category formation in autism.

There were also a number of other strengths of the current study. First, the current study included only one dot pattern category during the learning phase rather than two categories. Since most natural categories do not have a contrasting category, including only one category during the learning phase more closely replicates real life category learning. Also, as suggested earlier, the use of contrasting categories may allow individuals with autism to develop a strategy that allows them to learn subsets of dots that are maximally different between categories (or some other alternative strategy) as opposed to actually abstracting prototypes of the two categories during the training phase. Second, the stimuli included in the study all differed in subtle quantitative spatial variations rather than obvious spatial differences or feature differences that can be easily learned using alternative strategies. Finally, using dot patterns which are non-social in nature and involve no prior knowledge or experience provides information about the pure process of prototype and category formation and how individuals with autism deal with perceptual variability without any possible confounds of social difficulties or experience.

Even though the current study expands and improves on previous research on prototype formation and extends the results to a non-social category, there are some limitations. One limitation is that participants in the autism group were all high-functioning males. Therefore, the results may not generalize to the full spectrum of autism disorders or to females with autism. Another limitation that occurs in studies of cognitive abilities in high-functioning individuals with autism is that it is difficult to determine whether successful performance on the task reflects intact ability or whether alternative strategies or compensatory mechanisms are used to perform the task. The results of the current study should be replicated in other large samples of individuals with autism with a wide variety of ability levels to determine whether prototype formation deficits are domain general and extend to low-functioning individuals with autism. Future studies should also further examine the relationship between intelligence and prototype and category formation, and in particular, any different strategies that are used to succeed on these tasks.

While the current study revealed difficulties with prototype and category formation in individuals with autism, it is possible that the results are reflective of a more general difficulty with implicit learning and reduction of information into a summative or central representation. Research suggests that individuals with autism engage in different categorization processes than typically developing individuals and that these differences may be very basic and early developing (Klinger and Dawson 1995; Newell et al. 2010). Due to the critical role that implicit processes play in categorization and that categorization plays in understanding the world from birth, deficits could have major impact on real world functioning. An early deficit in the implicit learning mechanisms used to form prototypes could result in infants having difficulty decreasing the amount of information in a complex environment, possibly leading to overstimulation, avoidance of complex social information, or other aspects of autism. Therefore, addressing deficits in implicit learning mechanisms from very early in development may be an important avenue for intervention with individuals with autism. Although the current study is an important step and highlights critical methodological considerations for future research on prototype and category formation, many more studies need to be conducted to determine the exact role that prototype and category formation deficits and other implicit learning processes may play in the syndrome of autism.

Acknowledgments This study was supported by NIH/NICHD HD055748 and PA Department of Health SAP # 4100047862. The results presented here were submitted by Holly Zajac Gastgeb as part of her Ph.D. dissertation (Department of Psychology, University of Pittsburgh). We are grateful to Dr. Catherine Best, Dr. Keiran Rump, Sarah Hannigen, Desirée Wilkinson, Sara Green, and Kao-Wei Chua for testing participants involved in the current study and Dr. Carla Mazefsky for commenting on prior versions of the manuscript.

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