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Intact prototype formation but impaired generalization in autism

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ABSTRACT

Cognitive processing in autism has been characterized by a difficulty with the abstraction of information across multiple stimuli or situations and subsequent generalization to new stimuli or situations. This apparent difficulty leads to the suggestion that prototype formation, a process of creating a mental summary representation of multiple experienced stimuli that go together in a category, may be impaired in autism. Adults with high functioning autism and a typically developing comparison group matched on age and IQ completed a random dot pattern categorization task. Participants with autism demonstrated intact prototype formation in all four ways it was operationally defined, and this performance was not significantly different from that of control participants. However, participants with autism categorized dot patterns that were more highly distorted from the category prototypes less accurately than did control participants. These findings suggest, at least within the constraints of the random dot pattern task, that although prototype formation may not be impaired in autism, difficulties may exist with the generalization of what has been learned about a category to novel stimuli, particularly as they become less similar to the category's prototype.

1. Introduction

Cognitive processing in autism has been characterized by a difficulty with the abstraction of information across multiple stimuli or situations (e.g., Minshew, Meyer, & Goldstein, 2002; Ropar & Peebles, 2007) and subsequent generalization to novel stimuli or situations (e.g., Ozonoff & Miller, 1995; Swettenham, 1996). As shown in Table 1, this apparent difficulty in autism has led some to suggest that prototype formation, a process of creating a mental summary representation of multiple experienced stimuli that go together in a category, is also impaired. Impairment of prototype formation and/or its subsequent generalization to allow the categorization of novel stimuli in autism could lead to difficulties in applying what is learned to new objects or situations.

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Table 1
Studies of prototype formation in autism.

Research question	Results	Reference
Can children with ASD form prototypes?	TD children selected the prototype significantly greater than chance. Children with ASD and MR selected the prototype at chance levels	Klinger and Dawson (2001)
Can HF individuals with ASD demonstrate prototype formation through recognition?	Both groups of participants demonstrated prototype effects by: 1. Falsely recognizing prototypes to a greater degree than training stimuli, and 2. Recognizing stimuli to a decreasing degree as their similarity to the prototype decreased There were no group differences	Molesworth et al. (2005)
Can HF children and adolescents form prototypes, and does performance relate to explicit learning abilities?	Participants with ASD demonstrated less prototype learning than controls Measures of explicit reasoning correlated strongly with prototype formation in participants with ASD but weakly in controls Participants with ASD with low explicit reasoning scores performed poorly on prototype formation task, and those with high explicit reasoning scores performed well	Klinger et al. (2006)
Can task ambiguity lead to apparent prototype formation impairments in ASD?	Two-thirds of ASD participants demonstrated a prototype effect similar to controls; a subgroup, defined by poorer performance on the additional ambiguous task, did not demonstrate a prototype effect	Molesworth, Bowler, and Hampton (2008)
Can individuals with ASD form facial prototypes?	Participants in the ASD group did not demonstrate prototype formation as did the control group, and this effect was driven more strongly by adults than children	Gastgeb et al. (2009)
Can individuals with ASD form prototypes of unfamiliar stimuli?	Participants with ASD demonstrated a similar pattern of prototype formation as controls, although they took more trials to learn	Vladusich et al. (2010)
Do individuals with ASD show sensitivity to the degree of similarity between a category member and the category's prototype?	Children with ASD were less likely to endorse the prototype and demonstrated less sensitivity to the degree of distortion of the stimuli to the prototype	Church et al. (2010)

Abbreviations: ASD = autism spectrum disorder; HF = high-functioning; LF = low-functioning; MR = mental retardation; TD = typically developing.

Prototype formation outside of the autism literature has been examined extensively by a random dot pattern task (Posner, Goldsmith, & Welton, 1967). Participants are first shown distortions of a prototype during training and then tested on the prototype itself. It has been posited that through experience with the distortions, participants abstract or learn the central tendency, or prototype, even though the prototype itself is not presented (Posner et al., 1967). Participants then categorize new dot patterns based on their similarity to the learned prototype. The random dot pattern task has two advantages over previous tasks used to examine prototype formation in autism. The first is that the stimuli provide no single feature or set of features that unambiguously define a category, ensuring accurate performance is due to prototype formation based on all features, and not another strategy, such as a rule that relies only on a single feature shared by all category members. The second advantage of the random dot pattern task is that the stimuli contain features (i.e., the dots) that are all identical, limiting the information that may be used to determine category membership to the spatial relationship among the dots. Otherwise, idiosyncratic features may receive more attention than warranted, as has been widely reported in autism (e.g., Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Rimland, 1964; Rincover & Koegel, 1975).

Our study examined prototype formation in autism by use of the random dot pattern task while addressing possible methodological issues that may have impeded prototype formation in previous studies. For example, Klinger and Dawson (2001) and Molesworth, Bowler, and Hampton (2005) involved categories that could be easily distinguished by any one of a number of defining features, thereby allowing participants to categorize stimuli simply by forming a rule that all members of a category have a particular feature. Indeed, Klinger, Klinger, and Pohlig (2006) demonstrated in a follow-up study that participants with autism were likely using explicit learning processes, which support rule-based learning, when prototype formation requires a different type of implicit learning (e.g., Knowlton & Squire, 1993; Reber, Stark, & Squire, 1998).

Church et al. (2010) and Vladusich, Olu-Lafe, Kim, Tager-Flusberg, and Grossberg (2010) used the random dot pattern task or a variation of it, but participants were trained with corrective feedback after making a response. Maddox, Love, Glass, and Filoteo (2008) demonstrated that feedback can actually *hurt* learning of perceptual categories, such as in the random dot pattern task, by engaging the neural system supporting explicit, rule-based category learning. When feedback is provided in a perceptual category-learning task, the neural system supporting rule-based learning interferes with the neural system that more optimally supports perceptual learning. Rule-based category learning may be a more optimal means of learning categories for individuals with autism (Klinger & Dawson, 2001; Klinger et al., 2006), and switching from a rule-based learning neural system to a perceptual-based one may be even more problematic.

In the current study, participants with autism and typically developing controls were presented with three categories of random dot patterns that were distortions of three corresponding prototype patterns. Training phases involved presenting the patterns along with their category labels. During test phases, participants categorized previously seen training patterns and also new patterns. In a final test phase, previously unseen prototypes and new low- and high-distortions of those

Table 2
Definitions of prototype formation.

Categorization
1. Categorization accuracy of the previously unseen prototype to a similar or greater degree as familiar training and transfer stimuli (Knowlton & Squire, 1993; Reber et al., 1998; Smith & Minda, 2002)
2. Categorization accuracy of a stimulus that increases with increasing similarity to the prototype (Knowlton & Squire, 1993; Reber et al., 1998; Smith & Minda, 2002)
Recognition
3. Recognition of the previously unseen prototype to a similar or greater degree as familiar training and transfer stimuli (Posner & Keele, 1968)
4. Recognition of a stimulus that increases with increasing similarity to the prototype (Omohundro, 1981)

prototypes were also categorized. Participants also provided an "old" or "new" response, indicating whether they recognized each pattern. As outlined in Table 2, prototype formation in the current study was therefore operationally defined as accurate categorization or false recognition of the previously unseen prototype to a similar or greater degree as familiar training stimuli. It was also defined as categorization accuracy or recognition of a stimulus that increases with increasing similarity to the prototype. Finally, a subset of these participants underwent a functional magnetic resonance procedure to examine neural correlates of prototype formation.

2. Materials and methods

2.1. Participants

We recruited two groups of adult males, 27 diagnosed with an autism spectrum disorder and 25 typically developing controls. Of those with autism, one had difficulty understanding the instructions and two others were inattentive due to sleepiness, and were dropped, leaving 24 participants with autism (see Table 3). All participants had a full scale IQ (FIQ) of at least 80 as measured by the Wechsler Abbreviated Scale of Intelligence (WASI) or the Wechsler Adult Intelligence Scale, Third Edition (WAIS-III) There were no significant group differences in age or any components of IQ. Table 3 summarizes the participants' demographic characteristics.

2.1.1. Autism group

Participants in the autism group were recruited from the Utah Autism Research Program and selected on the basis of the Autism Diagnostic Interview-Revised (ADI-R; Lord, Rutter, & LeCouteur, 1994) and the Autism Diagnostic Observation Schedule-Generic (ADOS-G; Lord, Risi, & Lambrecht, 2000) diagnoses for an autism spectrum disorder. Participants in this group completed questionnaires that screened for abnormal developmental history and other medical conditions known to elicit autism-like symptoms. Participants were compensated with coupons for a free video rental.

2.1.2. Control group

Participants in the control group were recruited from psychology undergraduate courses at the University of Utah and were compensated with course extra credit. These individuals also completed questionnaires that screened for any history of an autism spectrum disorder in themselves or their immediate and extended families, developmental delays or learning disabilities, emotional or behavioral problems, neurological or neuropsychiatric conditions, and problems with drug abuse.

2.2. Materials

2.2.1. General display

The random dot pattern stimuli were embedded within a computer-based presentation and displayed via a data projector onto a wall. Projected images of the stimuli were embedded within a black rectangular frame 34 in. wide and 26 in. long. Participants were seated approximately 11 feet from the wall on which stimuli were projected.

Table 3
Demographic characteristics of autism and control groups.

	Autism group (N = 24)		Control group (N = 25)		p-Value
	M (SD)	Range	M (SD)	Range	
Age	25.17 (5.37)	18–36	24.76 (3.33)	21–31	.75
VIQ[a]	104.50 (16.58)	76–136	109.96 (11.68)	79–135	.19
PIQ	114.83 (9.88)	96–132	111.12 (10.74)	86–129	.22
FIQ	108.58 (11.10)	88–130	111.84 (11.42)	84–136	.32

[a] One control participant had a VIQ of 79; however, his FIQ was above 80 and thus he met the present criteria for "typically developing".

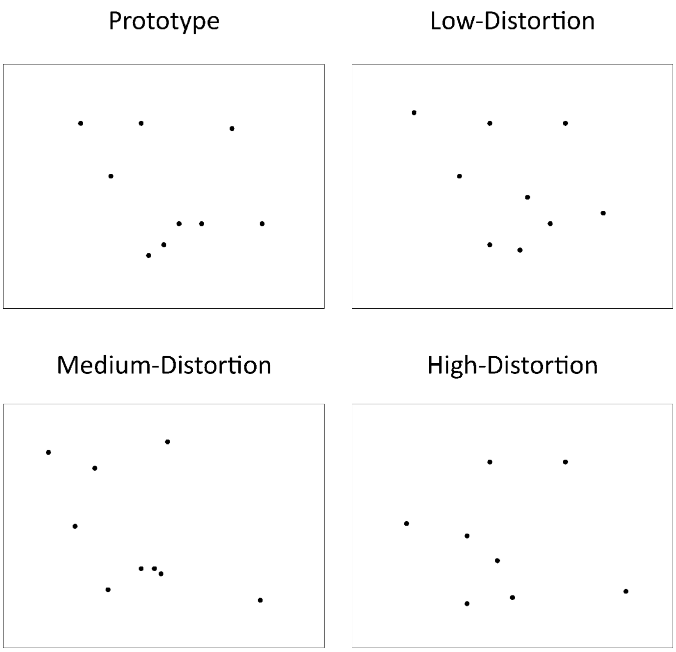

Fig. 1. The prototype pattern for one of the three categories and one each of the medium-, low-, and high-distortion patterns generated from the prototype.

2.2.2. Stimuli: Photographs Task

Stimuli for the Photographs Task, which was to train participants on the general procedures of the primary task, consisted of 12 digital photographs of dogs, people, and flowers taken by the first author of the current study. There were four photographs of stimuli from each category, three of which were assigned to the training subset and one assigned to the transfer subset.

2.2.3. Stimuli: random dot pattern task

Random dot pattern stimuli for the primary task were prepared using the method outlined in Posner et al. (1967), with the exception that the template for dot distortion consisted of a 441-cell area rather than a 400-cell area to allow for symmetrical distortion of the dots. As in Kolodny (1994), three prototype patterns, one for each of three categories, consisting of nine randomly distributed dots were each used to generate five stimuli for the training subset, five stimuli for the repeated-transfer subset, and four stimuli for the final-transfer subset (the prototype pattern was used as the fifth, final-transfer subset stimulus). The training and repeated-transfer stimuli were "medium" distortions of the prototype patterns; two of the final-transfer subset were "low" distortions, and two were "high" distortions. Levels of distortion in the current study mirrored those levels used by Kolodny for "low", "medium", and "high" and followed the corresponding procedure outlined by Posner et al. for creating distortions of 3, 6, and 7.7 bits per dot, respectively. Examples of some of the random dot pattern stimuli are displayed in Fig. 1.

2.3. Procedure

2.3.1. General procedure

Following consent, participants were given the Photographs Task, followed by the primary random dot pattern task. The Photographs Task was a training categorization task to familiarize each participant with the general procedure of the random dot pattern task and to determine whether the participant understood the procedure. The Photographs Task was repeated once for one participant in the autism group.

All stimuli were individually presented for 5 s and followed by a white screen. During training phases, the white screen was displayed for 2 s and automatically followed by the next stimulus. During test phases, the white screen remained until the participant responded. The experimenter manually initiated the display of the next stimulus once the participant provided a response, which was usually 1–2 s following display of the white screen. The order of presentation of stimuli was the same for all participants.

All participants were tested individually in a quiet room. The experimenter was present throughout the tasks to read instructions and record responses. During task phases, the lights to the room were turned off to improve visibility of stimuli. For each phase, a laminated response card with the respective response options for that phase was placed in front of the

Table 4
Structure for random dot pattern task.

1. Training phase 1
15 Training stimuli
2. Test phase 1
15 Training stimuli
15 Repeated-transfer stimuli
3. Training phase 2
15 Training stimuli
4. Test phase 2
15 Training stimuli
15 Repeated-transfer stimuli
5. Final test phase
15 Training stimuli
15 Repeated-transfer stimuli
15 Final-transfer stimuli (3 prototype, 3 low-distortion, 3 high-distortion)

participant, and he was told that it was acceptable to point to the correct response on the card in place of a verbal response. This card also served as a reminder of the possible responses for the current phase.

2.3.2. Photographs Task

The Photographs Task consisted of two phases: a training phase and a test phase. In the training phase, participants were presented with nine training stimuli, three from each of three categories, and the corresponding label of the category (A, B, or C) appeared in the upper left-hand corner. During the training phase, stimuli were grouped together so that the three stimuli belonging to category A were presented first, those from category B were presented next, and those from category C were presented last. Participants were instructed to try to learn which stimuli belonged with each letter because they would be asked to decide which category each stimulus belonged to in the next phase.

In the test phase, three of the nine training stimuli (one from each category) were pseudo-randomly intermixed with three transfer stimuli, again one from each category, so that six stimuli were presented in all. The letters for the categories were not displayed with the stimuli, and participants were instructed to say aloud the letter of the category to watch they thought each stimulus belonged.

2.3.3. Random dot pattern task

The procedure was drawn from Kolodny (1994) with slight modifications. There were five phases for each task. The first four phases consisted of alternating training and test phases, and the fifth phase was a final test phase. Table 4 summarizes this task structure.

The 15 training stimuli were presented during the two training phases as described in the Photographs Task above. In each of the two test phases, the 15 training stimuli were intermixed with the 15 repeated-transfer stimuli so that 30 stimuli were presented in all. A different order was used for each test phase. The letters of the categories were not displayed with the stimuli, and participants were instructed to say aloud the letter of the category they thought each stimulus belonged to.

In the final test phase, the 30 stimuli presented during the test phases (15 from the training subset and 15 from the repeated-transfer subset) were intermixed with the 15 final-transfer stimuli so that 45 stimuli in all were presented. Again, the letters of the categories were not displayed along with the stimuli. Participants were instructed to first decide whether each stimulus was old, meaning they had seen it before in any of the previous phases, or new, meaning they were seeing it for the first time in the current phase. Participants were then told that, after providing an ‘‘old’’ or ‘‘new’’ response, they should say the letter of the category to which they thought the stimulus belonged.

2.3.4. Functional MRI connectivity

Eight-minute resting BOLD acquisition was available for 16 of the participants with autism, as part of a separate study of brain development in autism (Anderson, Druzgal, et al., 2011). These data were utilized post hoc, for further description of the primary findings. Acquisition and postprocessing parameters, including motion correction, coregistration with MPRAGE, normalization to MNI template brain, PSTCor regression of CSF, white matter ROI, and soft tissue time series from each voxel, and low pass filtering between 0.001 and 0.1 Hz have been previously described (Anderson, Druzgal, et al., 2011). Five mm ROI's were selected in bilateral primary visual cortex (left: $x = -9$, $y = -91$, $z = -8$; right: $x = 9$, $y = -91$, $z = -8$). The remaining gray matter was parcellated into 7266 regions of approximately 5 mm in size (Anderson, Ferguson, Lopez-Larson, & Yurgelun-Todd, 2011; Anderson, Nielsen, et al., 2011). Functional connectivity was calculated between the averaged resting BOLD time series from bilateral primary visual cortex and all other brain regions. Correlation coefficient was then calculated between proportion correct categorization of the

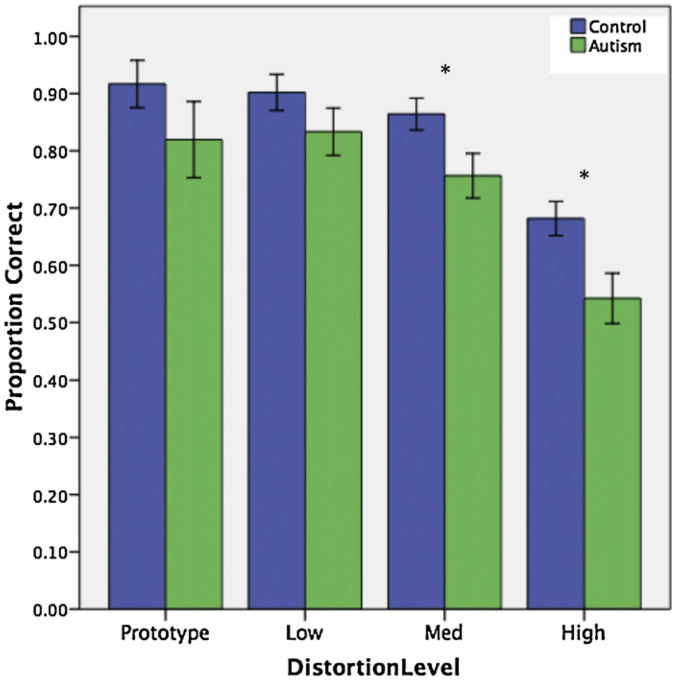

Fig. 2. Mean proportion of correct categorization responses for control (dark bars) and autism (light bars) participants for the stimuli presented in the final-test phase, including the combined training and repeated-transfer medium-distortion stimuli (medium) and each of the three final-transfer stimulus types: prototype, low-distortion (low), and high-distortion (high). Means and standard errors are represented. Asterisks indicate those distortion levels for which means differed significantly between groups at $p < .05$.

high-distortion stimuli from the random dot pattern task (outside of the scanner) and functional connectivity with the visual cortex across subjects for each ROI.

3. Results

3.1. Final test phase categorization

Fig. 2 displays mean categorization accuracy for each of the two participant groups in the final test phase. Means and standard deviations for these and all subsequent analyses are displayed in Table 5.

As can be seen in Fig. 2, the mean categorization accuracy (Definition 1) for participants with autism, like for control participants, was higher for the novel prototype patterns than for the combined familiar training and repeated-transfer patterns that make up the medium-distortion stimuli. A repeated measures ANOVA confirmed a main effect of stimulus type, $F(1,47) = 5.382$, $p = .03$, and no significant interaction between stimulus type and participant group, $F(1,47) = .068$, $p = .80$. Additionally, for both groups of participants, categorization accuracy decreased as distortion level increased (Definition 2). With distortion level converted to the number of bits change represented by each stimulus type (0 for prototype, 3.0 for low, 6.0 for medium, and 7.7 for high), linear regression analyses revealed that distortion level significantly predicted categorization accuracy for the control group, $b = -.026$, $t(98) = -4.529$, $p = .001$, and explained a significant proportion of the variance in categorization accuracy, $R^2 = .173$, $F(1,98) = 20.511$, $p = .001$. This was also true for the autism group, $t(94) = -3.740$, $p = .001$; $R^2 = .130$, $F(1,94) = 13.989$, $p < .001$. There was no significant interaction between participant group and distortion level in predicting categorization accuracy, $b = .006$, $t(192) = -0.607$, $p = .54$.

Table 5
Categorization and recognition performance (mean and SD).

	Prototype	Low-distortion	Med-distortion	High-distortion
Categorization: proportion correct				
Control	.92 (.20)	.91 (.15)	.87 (.14)	.69 (.15)
Autism	.82 (.33)	.83 (.20)	.76 (.19)	.54 (.22)
Recognition: proportion "old" response				
Control	.76 (.28)	.77 (.18)	.59 (.12)	.28 (.21)
Autism	.78 (.29)	.69 (.23)	.60 (.16)	.31 (.23)

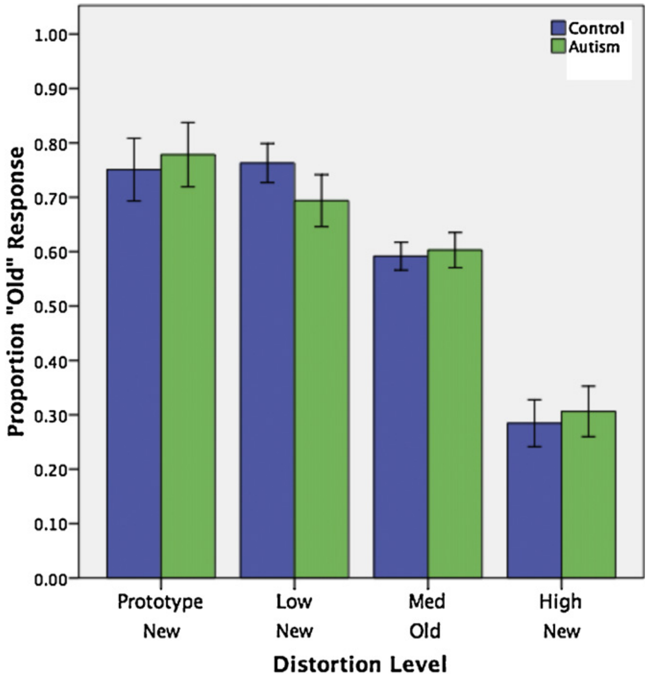

Fig. 3. Mean proportion of "old" responses for control (dark bars) and autism (light bars) participants for the stimuli presented in the final-test phase. Along the *x*-axis, below the label for each distortion level, is a second label of "old" or "new" to indicate the correct response for that stimulus type.

Fig. 2 further suggests that, despite the lack of group differences in the first two definitions of prototype formation, participants with autism may have had lower categorization accuracy for the medium- and high-distortion stimuli. Paired comparisons were computed for each stimulus type. No significant group differences were found for the prototype stimuli, $t(47) = 1.307$, $p = .20$, or the low-distortion stimuli, $t(47) = 1.422$, $p = .16$, but were found for the medium-distortion stimuli, $t(47) = 2.395$, $p = .02$, and the high-distortion stimuli, $t(47) = 2.776$, $p = .008$.

3.2. Final test phase recognition

Fig. 3 displays the mean proportion of "old" responses for each of the two participant groups in the final test phase. This figure suggests that both groups of participants falsely recognized the novel prototype patterns as "old" to a greater degree than they accurately recognized the familiar medium-distortion (training and repeated-transfer) stimuli as "old" (Definition 3). A repeated measures ANOVA resulted in a significant main effect of stimulus type, $F(1,47) = 19.137$, $p = .001$, and no significant interaction between stimulus type and participant group, $F(1,47) = .007$, $p = .93$. As with Fig. 2, distortion level was

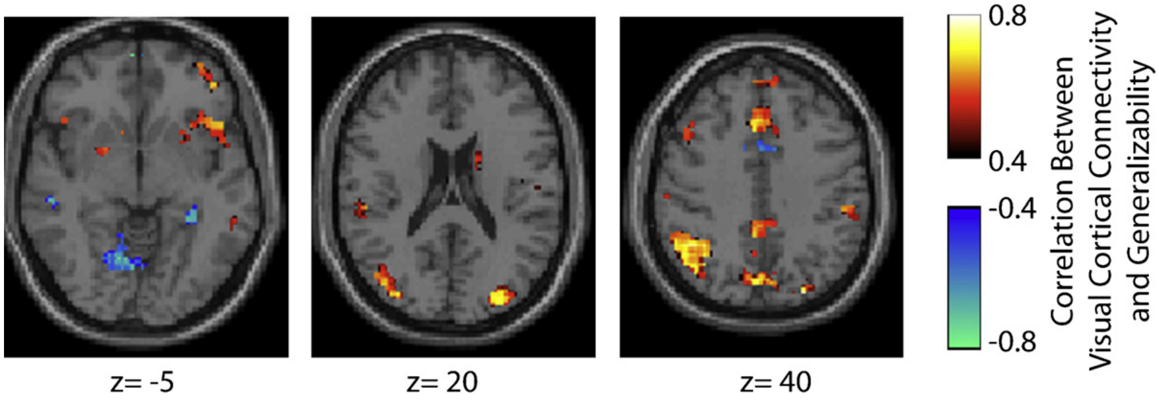

Fig. 4. Increased functional connectivity to primary visual cortex in subjects with improved generalizability. Images show correlation coefficient between connectivity to primary visual cortex and generalizability score for 16 subjects. Colored regions satisfied $p < 0.05$, uncorrected. Areas for which connectivity to visual cortex was most associated with subjects showing high generalizability included attentional regions: bilateral intraparietal sulcus, left frontoinsula, and supplementary motor area.

converted to the number of bits change represented by each stimulus type. Linear regression analyses revealed that distortion level significantly predicted recognition as "old" for the control group (Definition 4), $b = -.058$, $t(98) = -7.536$, $p = .001$, and explained a significant proportion of the variance in recognition as "old", $R^2 = .367$, $F(1,98) = 56.790$, $p = .001$. This was also true for the autism group, $t(94) = -6.472$, $p = .001$; $R^2 = .308$, $F(1,94) = 41.886$, $p = .001$. There was no significant interaction between participant group and distortion level in predicting recognition as "old", $b = .004$, $t(192) = 0.333$, $p = .74$.

3.3. Functional MRI connectivity

As noted above, participants with autism, as a group, categorized high-distortion stimuli significantly less accurately than control participants. Fig. 4 demonstrates the relationship between high-distortion categorization performance and visual cortical functional connectivity with the rest of the brain for 16 of the participants with autism. The colored areas satisfy $p < 0.05$, uncorrected, although no areas remained significant after correcting for multiple comparisons. Areas for which connectivity to visual cortex was most associated with participants categorizing high-distortion patterns with high accuracy included attentional regions: bilateral intraparietal sulcus, left frontoinsula, and supplementary motor area.

4. Discussion

Participants with autism formed prototypes of random dot patterns according to all four ways prototype formation was operationally defined. Furthermore, prototype formation in the autism group was not significantly different from that of controls. First, participants with autism categorized previously unseen prototypes reliably more accurately than familiar training and repeated-transfer stimuli. Second, participants with autism falsely recognized previously unseen prototypes to a reliably greater degree than they accurately recognized familiar training and repeated-transfer stimuli. Third, categorization accuracy increased as stimuli increased in similarity with the respective prototypes (i.e., decreased in distortion). Finally, recognition by participants with autism increased as stimuli increased in their similarity to the respective prototypes.

Plaisted, O'Riordan, and Baron-Cohen (1998) have argued that individuals with autism have a processing bias for discriminating features of stimuli and exhibit reduced processing of features held in common. In their task, control participants improved in their discrimination of highly similar stimuli with repeated exposure. Participants with autism, however, discriminated at high levels even prior to repeated exposure, suggesting that they did not initially perceive the stimuli as being as similar. It may be that stimuli that most typically developing individuals find similar are not as readily perceived as similar by individuals with autism.

For 16 of the participants with autism for which resting state functional connectivity data were available, areas for which connectivity to visual cortex was most associated with high categorization accuracy of high-distortion patterns included the attentional regions bilateral intraparietal sulcus, left frontoinsula, and supplementary motor area. Although these effects did not reach significance levels when correcting for multiple comparisons, they are in line with findings of reduced anterior–posterior functional connectivity in autism and the theory of cortical underconnectivity in autism (Cherkassky, Kana, Keller, & Just, 2006).

The present findings have important implications for Molesworth et al. (2005) and other studies that limit demonstration of prototype formation in autism to recognition performance. Both the participants with autism in the present study and those in the Molesworth et al. study demonstrated prototype formation through recognition, and Molesworth et al. concluded that no impairment was present in autism. However, in the current study, impairments were found in categorization performance. Had Molesworth et al.'s participants been given a transfer categorization test, they too may have demonstrated impairment.

The present findings stand in contrast to the conclusions reached by Klinger and Dawson (2001) and Gastgeb, Rump, Best, Minshew, and Strauss (2009). However, in addition to the methodological issues described above, the discrepancy could be due to assumptions about the cognitive processes involved in prototype formation. Klinger and Dawson compared prototype formation to the construction of a gestalt, in which the whole is an emergent property of the interrelations of its parts. Some theories of cognitive functioning in autism, such as weak central coherence (Frith, 1989; Frith & Happe, 1994), propose that gestalt, or holistic processing is impaired in autism, so Klinger and Dawson (2001) predicted prototype formation would therefore be impaired in their task. The interpretation of a prototype being a gestalt may be problematic, however. Gestalts are believed to be configurations of features that interact in a relational way, where the contribution of each feature to the larger whole depends on the characteristics of the surrounding features (see Kimchi, 1992). Take, for example, the Pac-Man shapes of the Kanizsa's triangle illusion, which together produce the appearance of the corners of a triangle. If one of the Pac-Man shapes were replaced by a full circle, the overall impression of a triangle would disappear. Another example is with faces- the stimuli used by Gastgeb et al. (2009). If the mouth of a face were replaced with another eye, for example, the overall impression would be less face-like. However, prototypes have often been described as consisting of independent features such that the contributions of one feature to the whole do not depend on the characteristics of the other features (e.g., Medin & Schaffer, 1978; Ross & Makin, 1999). A demonstration of this would be to replace one or more of the dots of one of the random dot patterns with any other sort of shape, such as a square. The result would be the same global pattern. If prototype formation does not involve the processing of relational information, theories like weak central coherence would not predict impairment in autism.

Two previous studies (Church et al., 2010; Vladusich et al., 2010) have utilized a random dot pattern task to examine prototype formation in autism. As mentioned above, the fact that both tasks provided feedback to participants about whether each stimulus had been accurately categorized could have interfered with learning. However, it is not clear why the participants with autism in the Church et al. study demonstrated impaired prototype formation and those in Vladusich et al. did not. One possible reason is that Church et al. used children whereas Vladusich et al., and the current study, used adult participants. Perhaps individuals with autism are better able to deal with competing neural systems as they reach adulthood. Another possibility is that the two groups of polygon stimuli that participants were trained to distinguish in the Church et al. study could actually be quite easily sorted on the basis of a simple rule.

The present findings are consistent with the finding of intact prototype formation by Vladusich et al. (2010). The current study more finely examines this issue by demonstrating that participants with autism may categorize random dot patterns at control accuracy levels when a pattern is more highly similar to the prototype, yet demonstrate impairment when a pattern is more highly distorted from the prototype. In other words, both the current study and that of Vladusich et al. demonstrate that prototype *formation* may be intact in autism, but the current study extends this to indicate that prototype *generalization* may be impaired in autism. Future research of prototype formation could benefit from tasks designed to better distinguish these two processes.

The present study has the advantage of utilizing a random dot pattern task that has been well-established as a means of assessing prototype formation without the interference of other strategies. However, it is limited in how well it can generalize to categorization in real-life. Much research supports a multi-process view of categorization and suggests that natural categorization cannot be fully accounted for by a single unitary mechanism (Medin, 1986; Medin, Altom, & Murphy, 1984; Patalano, Smith, Jonides, & Koeppe, 2001; Smith, Patalano, & Jonides, 1998; Smith & Sloman, 1994). It may be that in real-life categorization, impairments are seen in individuals with autism when they are not able to draw on additional cognitive resources available to typically developing controls.

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