VISUALLY GUIDED PROTOTYPE LEARNING IN CHILDREN WITH AUTISM SPECTRUM DISORDER

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ABSTRACT

(Under the direction of Laura G. Klinger)

Cognitive impairments in both categorization and attention have been found in individuals with Autism Spectrum Disorder (ASD). Individuals with ASD may have difficulty forming prototypes because of difficulties attending to all the relevant features in category members. This study examined prototype learning with cartoon animals in 18 children with ASD and 16 children with typical development. A prototype task was manipulated to either include visual cues to the relevant features of the stimuli or not include those cues. Results indicate that as a group, individuals with ASD performed more poorly than individuals with typical development in the prototype task and spent less time attending to relevant features in the animals. When a visual cue was added to the relevant features, groups did not differ in their performance or attention relevant features. These results suggest impairments in both attention and other cognitive processes may relate to impairments in categorization in ASD.
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<tr>
<td>ASD</td>
<td>Autism Spectrum Disorder</td>
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<tr>
<td>NVC</td>
<td>Non-visual cue condition</td>
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Categorization skills are extremely important in everyday life. The ability to organize information into conceptual groupings allows individuals to make inferences about new information based on previously formed concepts or categories. Without an ability to categorize new information based on past experiences, we would be overwhelmed by the novelty in our everyday environments. Thus, the ability to categorize allows for a decreased demand on memory and learning which, in turn, allows for one to engage more with their surrounding environment (Markman, 1991). It is believed that in typical development, individuals store an average representation (i.e., a prototype) of an object in their memory rather than an image for every single member of the category (Posner & Keele, 1968). For example, when a person recalls a “cat,” that person likely does not visualize every single cat they have previously seen. Rather, a general representation of what a cat looks like may be visualized (e.g., has 4 legs, a tail, whiskers, pointy ears, etc.). Infants with typical development are able to form categories based on facial (Strauss, 1979) and cartoon animal (Younger, 1985, 1990) prototypes by 10 months of age. This process is believed to be relatively automatic and is viewed as a type of implicit learning (Eigsti & Mayo, 2011; Klinger, Klinger, & Pohlig, 2007).

Without the ability to create categories through this type of automatic abstraction process, the world would be very difficult to understand. Interacting with the environment would require additional cognitive effort and the world would be an overwhelming place. As a result, important and necessary social opportunities and interactions may be lost or may not be the primary focus of an individual. Research has hypothesized that prototype learning is one area of cognitive impairment in individuals with Autism Spectrum Disorder (ASD; Gastgeb, Dundas, Minshew, & Strauss, 2012; Gastgeb, Rump, Best, Minshew, & Strauss, 2009; Gastgeb, Strauss,
Categorization in ASD

ASD is a neurodevelopmental disorder that presents symptoms by 12 months of age and can be diagnosed as early as 18 months (Ozonoff et al., 2010). Some early behavioral symptoms of ASD include impairments in social-emotional reciprocity, difficulty making eye contact and strict adherence to routines (American Psychiatric Association, 2013). Klinger et al. (2007) suggested that these behavioral symptoms resulted from underlying cognitive impairments from the first year of life. One important early-developing cognitive ability that has been proposed to be impaired in persons with ASD is categorization, specifically prototype learning.

Finding impaired prototype learning in ASD would provide evidence of an early cognitive impairment that could have long term implication on development. Indeed, impaired prototype learning could explain some of the social and language difficulties that characterize ASD. By developing prototypes, individuals can easily identify a previously unseen member of a category, effectively simplifying the environment and reducing the memory load on the individual. As a result, one can focus on social interactions and other important aspects of the environment for new learning opportunities (Rosch, 1978). However, the literature on prototype learning in ASD has shown mixed results. Early studies indicate impaired prototype learning in ASD (Klinger & Dawson, 2001), however these results have not been consistently replicated. Some studies have shown intact prototype learning in ASD (Molesworth et al., 2008;
Molesworth et al., 2005) while others have shown impairment (Gastgeb et al., 2009, 2006, 2011).

Impairments in prototype learning in ASD have been demonstrated using a variety of stimuli including facial (Gastgeb et al., 2009, 2011), cartoon animals (Klinger et al., 2007; Klinger & Dawson, 2001), and dot pattern (Gastgeb et al., 2012) prototypes. Klinger and Dawson (2001), for example, found that individuals with ASD performed at chance (54%) in a prototype task with cartoon animals and children with typical development performed above chance (79%) demonstrating an impairment in prototype learning in ASD.

Some researchers have argued that impairments in prototype learning are more a function of developmental delay than specific to ASD (Molesworth et al., 2008; Molesworth et al., 2005). This argument was based on the fact that the first study documenting prototype impairments in children with ASD included individuals who also had intellectual disability (Klinger & Dawson, 2001). Subsequent studies using individuals with high functioning ASD have been mixed, with Molesworth and colleagues (2005; 2008) finding intact prototype learning in individuals with ASD who did not have intellectual disability and others finding impairments in prototype learning in high-functioning children and adults with ASD (Gastgeb et al., 2012, 2009, 2006, 2011; Klinger et al., 2007; Vladusich, Olu-Lafe, Kim, Tager-Flusberg, & Grossberg, 2010) indicating that intellectual functioning is not related to the ability to form a prototype. The mixed results of these studies indicate that other factors, outside of intellectual ability, may be influencing prototype learning in ASD.

Studies that have shown intact prototype learning may not be representative of true prototype abstraction due to differences in study design. For example, Vladusich and colleagues (2010) included an extensive training phase in which participants were provided feedback and
were unable to continue with the test trials until they achieved 75% correctness. The feedback in the training phase allows for participants to consciously and explicitly form categories, rather than forming the categories more implicitly. The prototype tasks used by Molesworth et al (2005; 2008) also found intact prototype learning in high functioning individuals with ASD. However, their study used more obvious features with less subtle variation within those features. Because of these differences in stimuli, individuals with ASD may have been able to memorize the exact characteristics of the category, rather than implicitly abstract the prototype. Klinger, Klinger, and Pohlig (2007) suggested that individuals with ASD, particularly adolescents and adults, may complete prototype learning tasks using a more explicit, effortful approach compared to the more implicit, automatic approach used by individuals with typical development from infancy onward. This hypothesis could explain discrepancies in the literature due to verbal reasoning skills characterized by intellectual functioning (IQ) and/or tasks that facilitated reasoning through the study design. The inconsistency in the literature on prototype learning in ASD suggests that further research is needed that examines not only the ability to learn the prototype, but also the underlying cognitive mechanism that may be driving this atypical pattern of categorization. One possible cognitive mechanism that is related to categorization is attention.

**Attention in ASD**

Attention is another early cognitive impairment in ASD (Allen & Courchesne, 2001; Ames & Fletcher-Watson, 2010; Leekam & Moore, 2001). Research suggests that individuals with ASD have difficulty attending to important aspects of their environment that allow them to learn things such as social skills, language, and other daily-life skills.

Several theories about attention impairments in ASD could also be linked to impaired categorization in this population. One idea is that individuals with ASD have a “sticky attention”
mechanism that makes it difficult to disengage, shift, and re-engage their attention in a given situation. For example, Landry and Bryson (2004) found that children with ASD took more time to disengage from a fixation point and shift their attention to a novel stimulus compared to children with Down syndrome and children with typical development. This impairment in disengagement was especially pronounced when the fixation point remained visible when the novel stimulus appeared. Courschene, Townsend, and colleagues (1994) also found that individuals with ASD and individuals with cerebellar regions were more impaired than typically developing individuals when required to rapidly and accurately shift their attention. This impairment in disengaging and shifting attention in ASD may affect categorization when individuals with ASD have difficulty attending to the entire object, person, or environment when they get “stuck” on one part of the stimulus. Indeed, prototype learning necessitates attending to all relevant category stimuli.

A second theory of impaired attention in ASD is that these individuals have an atypical attention spotlight. The spotlight could be either too narrow such that the individual is focusing on details rather than the entire picture (e.g., the “trees rather than the forest”) or it could be too broad of a spotlight with too many distractors that prevent focus on important information (e.g., the “forest rather than the trees”). Literature has proposed two possible cognitive mechanisms that drive the narrow attention spotlight in ASD—the concept of weak central coherence (Happé & Frith, 2006) and enhanced perceptual functioning (Mottron, Dawson, Soulières, Hubert, & Burack, 2006; see Travers, Klinger, & Klinger, 2011 for review). Weak central coherence suggests a global processing deficit where individuals with ASD tend to focus on the small details and have difficulty incorporating the details into the big picture. Enhanced perceptual functioning, on the other hand, proposes that individuals with ASD are still able to process things
on a global level, but have a general tendency to focus on the smaller details. Both of these concepts propose that individuals with ASD have a narrower attention spotlight compared to typically developing individuals which can impact how they interact with their environment. In contrast, Burack (1994) suggests that individuals with ASD may have too broad of an attention spotlight. Individuals with ASD had particular difficulty identifying a specific shape in the presence of distractors indicating that they were using a broader attention spotlight. However, when the visual search area was smaller, individuals with ASD were able to locate the target more quickly. Travers, Klinger, and Klinger (2011) suggest that the discrepancies in the attention spotlight literature are a result of an underlying difficulty shifting between a narrow and broad attention spotlight in ASD. This ability to control a spotlight is important to prototype learning because one must attend to all the relevant details of a new category member in order to create a best image or a prototype. Both the impairments in attention spotlight and disengage and shifting of attention suggest that something is impaired in the efficient allocation of attention (movement of attention from one location to another or movement of attention from a broad to a narrow view) in ASD. This impairment in attention allocation may impair prototype learning because individuals with ASD are not able to attend to all the relevant features of the stimuli. Unless attention is allocated to the entire stimulus array (e.g., the entire cat), it would be difficult to form a prototype that accurately represents the category (e.g., a focus on the tail would make it difficult to create a prototype that includes other relevant features such as whiskers).

Gastgeb and colleagues recently examined whether attention indeed is related to prototype learning in both a facial prototype task (Gastgeb et al., 2011) and a dot pattern prototype (Gastgeb et al., 2012). In both studies, individuals with ASD showed difficulty forming prototypes. Eye-tracking data from these studies indicated that individuals with ASD
exhibited a similar pattern of attention as participants with typical development in the prototype task. This suggests that impairment in prototype learning may not be related to an underlying attention deficit in ASD. However, an unpublished Masters Thesis (Klein, 2006) that also examined eye-gaze behavior in a cartoon animal prototype task with adolescents with ASD found that impairment in prototype learning was related to attention allocation in persons with ASD. Specifically, individuals with ASD looked less often at the relevant features compared to individuals with typical development. More research is needed to further examine the role of attention in prototype learning in ASD with a focus on change in prototype learning when attention is manipulated.

**Present Study**

The aim of the present study is to examine the role of attention allocation in prototype learning in individuals with ASD. Specifically, the present study examined 1) whether individuals with ASD show atypical attention during a prototype learning task and (2) whether they are able to better perform in a prototype task with the addition of a visual cue that specifically allocates attention to relevant features. Based on the previously discussed attention theories, children with ASD may get “stuck” and have difficulty shifting their attention and focusing on several features in a given prototype. One way to aid their exploration of a stimulus is to provide overt, visual cues that can facilitate a shift of their attention to the important features of a stimulus, which in turn, can help form a general category.

*Hypotheses*

1. In the typical prototype task, children with ASD will show decreased prototype learning compared to children with typical development matched on verbal IQ.
2. When visual cues are included to highlight important features of the novel animal, children with ASD will show increased prototype learning. In this condition, it is predicted that children with ASD will not differ from children with typical development.

3. Across diagnoses, individuals that show increased attention (i.e. fixation duration, frequency of fixation, and features examined) to relevant features measured by eye gaze will show increased prototype learning.

Method

Experimental Design

This study was a 2 x 2 x 3 factorial design. There were two diagnostic groups (ASD and Typical), two attention conditions (with and without visual cues), and three trial types (familiar animal, novel animal, prototype animal). The attention conditions and trial type variables were the within subject variables and diagnostic groups was the between subjects variable. The dependent variables were participant responses about whether an animal was familiar or novel. In addition, analyses were conducted on eye gaze to the relevant, changing features of each animal family in each condition during the test trials (i.e., fixation time, number of fixations, and number of relevant features attended to).

Participants

The final sample included eighteen children (8 years, 0 months to 14 years, 1 month) with high functioning ASD and 16 children (8 years, 2 months to 14 years, 2 months) with typical development participated in this study. The Autism Diagnostic Observation Schedule-Second Edition (ADOS-2; Lord et al., 2012), Module 3 was administered to all children with ASD to confirm a diagnosis. For those children who completed an ADOS-2 administered by the author in the previous 18 months and met criteria for a diagnosis, the ADOS-2 was not repeated.
Parents of participants completed the Social Responsiveness Scale, Second Edition (SRS-2; Constantino, 2012) in order to screen for ASD symptomatology in children with typical development and to measure current symptom severity in the children with ASD. Finally, only participants with a score of 85 or above on the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) were included in the present study.

Children with ASD were excluded if they had a known genetic disorder that has been linked with ASD (i.e. Fragile X, Down syndrome, tuberosclerosis). Children with typical development were excluded if they have a family member with ASD (i.e. sibling, parent, cousin) and/or they have comorbid neurological or developmental disorder (e.g. Specific Learning Disorder, ADHD, Specific Language Impairment etc.).

Groups were matched on chronological age as well as Verbal IQ, Performance IQ, and Full Scale IQ from the WASI (See table 1). Twenty-one participants with ASD were initially tested and two of those participants were removed from analyses due to a low IQ score (VIQ<85). One additional participant with ASD was removed from the sample because her scores on the experimental task were more than 2 standard deviations outside of the average scores of both groups of participants. Finally, two participants with typical development were removed from the sample because of an extremely high IQ score (FSIQ=140), 2 standard deviations above the average scores for the group.

Participants with ASD were recruited through the Autism Research Registry at the University of North Carolina and the UNC employee list serv. In addition, children who had previously participated in research programs at the TEACCH Autism Program were contacted about this research opportunity. Children with typical development were recruited through community fliers, list servs in the local community and UNC, and the Research Registry.
**Measures**

**Autism Diagnostic Observation Schedule—Second Edition (ADOS-2; Lord et al., 2012)**

The ADOS-2, Module 3, is a semi-structured play assessment of social interaction, communication, repetitive behaviors and restricted interests, and imaginative or symbolic play administered to children and adolescents (ages 4-16 years) who may have autism spectrum disorder. The assessment is scored using a standardized algorithm based on scores from the communication, reciprocal social interaction, and restricted and repetitive behavior domains. Good criterion validity and reliability ratings have been demonstrated, with a mean weighted kappa ($M_{kw}=.65$) for items in Module 3.

**Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999)**

The WASI is an abbreviated IQ measure for individuals six to 89 years and takes approximately 30 minutes to administer. The WASI provides a verbal IQ (vocabulary and similarities subtests), a performance IQ (block design and matrix reasoning subtests), and a full-scale IQ. The WASI has good validity and reliability (reliability coefficients for children range from .81 to .96).

**Social Responsiveness Scale, Second Edition (SRS-2; Constantino, 2012)**

The SRS-2 is a 65-item parent report questionnaire that examines ASD symptoms. Participants scoring higher on the SRS indicate a greater level of severity in social impairment. Parents rate their child’s social reciprocal skills on a scale from 0 (never true) to 3 (almost always true). The test-retest reliability is $r = .88$ after 3 months and $r = .83$ after 27 months.

**Demographic Form**

Parents completed a demographic form about their child that included questions about the child’s age, sex, race, ethnicity, and any current diagnoses.
Stimuli

The stimuli consisted of black-and-white drawings of imaginary animals. There were six different animal families, three of these animal families were in the no-visual cue (NVC) condition and three families were in the visual cue (VC) condition. Assignment of animals to the NVC and VC conditions was counterbalanced to insure that results were not linked to a specific stimuli set. Each animal family was similar in complexity (e.g., equivalent number of features) and was given a novel one-syllable name (e.g. MIP, DAK).

Animals were created following the methodology described by Younger (1985; 1990). Within each category of animal, four features varied along five quantitative dimensions. For example, members of the “MIP” family varied in ear width, feet length, wing length, and mouth width (See Figure 1 for MIP example). Each feature varied along five discrete values. For example, in the MIP family, the smallest wing length was designated 1 and the longest as 5.

Familiarization stimuli were developed such that children were shown animals composed of feature values 1, 2, 4, and 5 twice during the familiarization trials. The features associated with value 3 were not shown during familiarization trials. However, the figure composed of all value 3 features is the mathematical average (i.e. the prototype) of the previously seen animals. This prototype animal was shown during the test trials along with animals from the familiarization trials and novel animals. The novel animals were composed of the same features that have been seen previously, but in new combinations.

Apparatus

Eye-tracking hardware and software: Stimuli were presented using Tobii Studio 2.0 on a Tobii 1750 eye-tracker using binocular tracking at a rate of 60 Hz. The binocular tracking tracks both eyes simultaneously and automatically determines left eye versus right eye regardless
of head position and blinking. The eye-tracking system is easily calibrated (approx. 1 min) and allows for free head movement. There is no head-mounted apparatus, making it ideal for children.

Procedure

Participants were scheduled for a two-hour session at the UNC TEACCH Autism Program and the Carolina Institute for Developmental Disabilities (CIDD). During this session, parents signed a consent form and children signed an assent form. Participants with ASD completed the ADOS-2 and the WASI while the parent completed the SRS-2 and the demographic form. Participants with typical development only completed the WASI while the parent completed the SRS-2 and the demographic form.

Eye-tracking. Children were told that we were interested in how children learn and that we were going to test their memory for animals. They sat approximately 60 cm away from the Tobii 1750 and the center of the screen was adjusted to be at eye-level. While the Tobii eye-tracking system can accommodate some head movement, participants were asked to stay as still as possible and watch the screen. First, participants completed the calibration sequence which included watching a red dot move around to 5 different areas of the screen for approximately 30 seconds. If eye-tracker did not successfully calibrate the participant’s eye movements, the sequence was repeated and participants were reminded to “watch the red dot” or “follow the red dot” while keeping their head still. Participants were asked to complete the sequence up to two additional times for a maximum of three sequences, if needed. All participants completed the calibration within three sequences. All participants were recalibrated if they left the room for a break.
Four Areas of Interest (AOIs) were created for each trial within each animal category. These AOIs were based on the four features that varied within each animal category. For example, AOIs for the MIP included the ears, arms/wings, mouth, and feet as those features were relevant in creating a prototype. AOIs were drawn slightly larger than the features in order to account for one degree of visual angle. Within each trial, total time of fixation and number of fixations for each AOI were calculated during the test phase of the study.

**Experimental task.** After completing the calibration sequence, participants completed the no-visual cue (NVC) prototype tasks for three sets of animal categories. The NVC condition was based on the task used in Klinger and Dawson (2001). Within each family, there were 8 familiarization trials, each presented for eight seconds (See Figure 1). The order of these eight familiarization trials was counterbalanced across participants. Participants were told the name of the animal category (e.g., “This is a MIP”) during each of the familiarization trials. Following the familiarization trials there were 9 test trials. Three types of stimuli were presented at test: familiar animals (animals seen during familiarization), novel animals from the same category (animals made of previously seen features in a novel combination), and the prototype animal (an animal that is the average of the features seen during familiarization). For each test trial participants were asked if they had seen this member of the animal family before and respond with “yes” or “no.” A response of “yes” to the prototype animal is a false memory because the participant actually had not seen the prototype before. This type of false memory was considered evidence of prototype formation. Eye gaze was recorded during these test trials to measure the number of fixations and amount of time spent looking at the crucial varying features (e.g., ear width, feet length, wing length, etc.) of each animal. Participants completed this task for three animal families. Their answers were recorded by the experimenter.
In the visual cuing (VC) condition, the same protocol was used, except three new animal categories were used and the stimuli for the familiarization trials had added visual cues that highlighted the relevant features for each animal family (See Figure 2). Each of the four relevant features for an animal family was highlighted for one second during each familiarization trial. For example, a MIP varies on ear width, wing length, foot length, and mouth size. Each of the 8 familiarization trials for the MIP was first presented for two seconds without any features highlighted followed by the same stimulus with a relevant feature highlighted (e.g., the ears were highlighted). Each stimulus with a relevant feature highlighted was presented for one second for a total of four additional seconds and ending with a MIP without any highlighted features for two seconds. Thus, each familiarization stimulus was presented for a total of eight seconds, the same presentation time used in the NVC condition. Highlighted features were presented in a counterbalanced order. After completing eight familiarization trials, participants completed test trials in the same manner as the NVC condition. No visual cuing was added to the VC test trials. The VC condition was always administered after the NVC cue condition because of concerns that it would influence performance on the NVC condition. That is, after completing the VC condition participants may have become consciously aware of the relevant features that change. Thus, it is possible that this exogenous manipulation of attention would influence performance on a later task that no longer highlighted the relevant features (NVC). In order to control for order and potential animal effect, the order of animals was counterbalanced both across and within condition.

Participants were allowed to take breaks between each animal category if needed, but were encouraged to complete the entire NVC condition before taking a break. Each animal category took less than 5 minutes for a total of 30 minutes across both conditions. After the
visual cuing condition, participants were asked if they had a certain strategy for answering during the test trials (e.g. “Why did you say ‘yes’ when you did?”) and then asked if this strategy changed as they learned more animal categories.

**Results**

*Prototype Task Performance*

Recognition responses (i.e. participants indicate they have previously seen an animal) were recorded for each test trial stimulus. The mean percent of recognition was calculated for familiar (old), novel, and prototype stimuli across all animal categories. Both novel and prototype stimuli were “new” as neither had been seen during familiarization. For each condition, the mean percent of recognition to the novel animals was subtracted from the mean percent of recognition from the prototype animal to obtain a prototype effect score. A higher score indicates more “yes” responses (false positives) to the prototype than the novel animals. Means were examined separately for each condition and are presented in Table 2. Results for each condition, the non-visual cue (NVC) and the visual cue (VC) condition, were collapsed across the three animal categories presented for each condition to create overall averages for each condition.

In the NVC condition, individuals with typical development recognized the prototype 47% (SD=22%) more than the new animals compared to 34% (SD=28%) in the ASD group. In the VC condition, individuals with typical development recognized the prototype 40% (SD=27%) more than the new animals compared to 38% (SD=27%) for the individuals with ASD. To compare performance across conditions, a 2 X 2 X 3 mixed ANOVA was performed using the response data from the test phase with diagnosis as a between subject variable, condition (NVC vs. VC), and stimulus type (old, new, and prototype) as the within subjects variable. A significant main effect of stimulus type was observed, $F(2,32)=76.30$, $p<.001$,
indicating that across all participants, recognition responses were higher to the prototype stimuli (mean=89.5%) than to either the old (mean=62.8%) or new (mean=50.3%) stimuli. Follow-up t-tests indicated that participants recognized the prototype significantly more than the old animals, \( t(33)=10.39, p<.001 \), and recognized the old animals significantly more than the new animals, \( t(33)=4.75, p<.001 \). The main effect of condition was not significant, \( F(1,32)=.81, p=.45 \), revealing that there was no difference in how participants responded to the test animals across the NVC and VC conditions. The main effect of diagnosis was not significant \( F(1,30)=62, p=.44 \), revealing that diagnostic groups did not differ in their responses to the animals. Neither the two-way interaction between diagnosis and condition, nor the three-way interaction between diagnosis, stimulus type, and condition were significant, \( F(1,32)=.004, p=.95 \), and \( F(2,31)=.068, p=.62 \) respectively. Overall, both groups showed a significant prototype effect in the NVC and the VC conditions.

Follow-up independent samples t-tests on the prototype effect were conducted to further examine the hypothesis that individuals with ASD would show decreased prototype learning in the NVC condition compared to individuals with typical development, \( t(32)=1.46, p=.08, d=.51 \), one-tailed. This statistical trend indicates that individuals with typical development more frequently provided a false positive response to the prototype compared to individuals with ASD. While not statistically significant, the medium effect size indicates that a diagnostic difference may emerge with increased sample size to increase statistical power. In the VC condition, an independent samples t-test indicated no significant difference and a small effects size comparing the mean prototype effect between individuals with typical development and individuals with ASD, \( t(32)=.21, p=.40, d=.07 \).
We also examined the relationship between the size of individual’s prototype effect and verbal ability measured by verbal raw scores from the WASI. In the non-visual cuing condition, the prototype effect score was positively related to raw verbal scores for participants with ASD, \( r(16) = .47, p = .05 \). While not statistically significant, the same pattern was shown for participants with typical development, \( r(14) = .37, p = .16 \). Interestingly, the positive relationship between prototype effect and verbal raw scores did not appear in the cuing condition, ASD: \( r(16) = .27, p = .39 \); Typical: \( r(14) = .002, p = .99 \).

Eye-Tracking Results

Eye-tracking data recorded during the test trials of the prototype task were examined. Only the first three seconds of eye-gaze for each trial was analyzed as the trial length varied for each individual. Within each test trial, individuals with ASD and typical development did not differ in their overall eye gaze. On average for each test trial, the fixation duration individuals with ASD was 1.60 seconds compared to 1.79 seconds for individuals with typical development, \( t(32) = 1.05, p = .30 \). The average number of fixations was 4.9 fixations per trial for the ASD group and 5.3 fixations per trial for the typical group, \( t(32) = 1.25, p = .22 \).

Three summary scores were created to measure visual attention to AOIs. Each measures a different attention construct and thus was analyzed separately. First, an AOI fixation duration measure was calculated to assess the length of time that participants looked at relevant features relative to their overall attention duration. This was calculated as Total Fixation Duration on AOIs divided by Total Fixation Time creating a proportion measure of attention on AOIs. This is a measure of sustained attention. Second, an AOI fixation frequency measure was calculated to assess the number of times participants fixated on the AOIs relative to the entire animal. This was calculated as Total Fixation Frequency on AOIs divided by Total Fixation Frequency on the
entire animal. This score is related to attention shifting as decreased shifting would result in fewer unique fixations. Lastly, the number of AOIs participants attended to was calculated to assess how many relevant features were attended to. This was calculated by determining how many relevant features participants fixated on in each trial, averaging this across each animal and within each condition. Given that there are four relevant features in each animal, the total possible score for this measure is 4. Individual test trials where the individual made 0 or 1 fixations to AOIs were not included in analyses due to limited data within that trial. This is a measure of attention as a result of learning which features are relevant. Means for all eye-tracking measures for each group in both conditions are presented in Table 3.

**Fixation Duration Results.** Overall, the proportion of fixation duration on AOIs was not different between groups; the typical group spent 65% (SD=5%) of their time looking at the AOIs compared to 62% (SD=6%) for the ASD group. Data was analyzed separately for each condition. In the NVC condition only, individuals with typical development spent 66% of their time (SD=10%) looking at AOIs compared to 60% (SD=10%) for individuals with ASD. On the other hand, in the VC condition the proportion of fixation duration on AOIs was 64% (SD=9%) for the typical group and 64% (SD=11%) for the ASD group. To compare the proportion of time spent looking at AOIs, a 2 X 2 mixed ANOVA was performed to examine the proportion of fixation duration on AOIs; diagnosis as a between subject variable, and condition (NVC vs. VC) as the within subjects variables. The main effect of condition was not significant, $F(1,32)=.19$, $p=.66$, indicating that there was no difference in overall proportion of looking time on AOIs between conditions. The main effect of diagnosis was marginally significant $F(1,32)=3.38$, $p=.08$, suggesting that children with ASD spent a smaller proportion of their time looking at AOIs. There was no significant interaction effect of condition and diagnostic group,
indicating that there was no significant difference in fixation time on AOIs within a diagnostic group between the conditions. A follow-up independent samples t-test was conducted to further examine the hypothesis of individuals with ASD spending less time examining AOIs during the NVC condition revealing a trend for group differences in the NVC condition, $t(32)=1.92, p=.06, d=.60$. This effect did not hold true when examining the VC condition, $t(32)=.09, p=.93, d=.00$, indicating that gaze behavior between groups was more similar in the VC condition.

**Frequency of Fixations Results.** When examining the number of fixations, the proportion of fixations on AOIs across both conditions was 63% (SD=5%) for individuals typical development compared to 58% (SD=5%) for individuals with ASD. In the NVC condition, 64% (SD=9%) of fixations made by individuals with typical development were on AOIs compared to 57% (SD=8%) for the ASD group. In the VC condition, the proportion of fixations made on the AOIs was 62% (SD=7%) for the typical group and 58% (SD=8%) for the ASD group. To further compare the proportion of fixations on AOIs, a 2 X 2 mixed ANOVA was performed with diagnosis as a between subject variable, and condition (NVC vs. VC) as the within subjects variables. The main effect of condition was not significant, $F(1,32)=.14, p=.71$, indicating that there was no difference in overall proportion of looking time on AOIs between conditions. The main effect of diagnosis was significant $F(1,32)=8.00, p=.008$, revealing that diagnostic groups differed in the overall proportion of fixation on AOIs. Children with ASD showed significantly fewer fixations across both conditions compared to children with typical development. The was no significant interaction effect between diagnosis and condition, $F(1,32)=.61, p=.44$. To examine original hypotheses regarding group differences in each condition, independent samples t-tests were conducted. In the NVC, individuals with ASD showed fewer fixations on the AOIs
compared to individuals with typical development, \( t(32)=2.11, p=.04, d=.82 \), whereas there were no group differences in fixations in the VC condition, \( t(32)=1.22, p=.23, d=.53 \).

**Number of Features Attended Results.** The number of AOIs an individual fixated on at least once during each trial was also examined. In the NVC condition, individuals with typical development fixated on 2.29 features or AOIs (SD=.51) compared to 2.01 features for individuals with ASD. In the VC condition individuals with typical development fixated on 2.06 (SD=.34) features compared to 1.98 (SD=.45) features for individuals with ASD. To further compare the average number of features attended to in a single trial, a 2 X 2 mixed ANOVA was performed with diagnosis as a between subject variable, and condition (NVC vs. VC) as the within subjects variables. The main effect of condition was not significant, \( F(1,32)=2.86, p=.10 \), indicating that there was no difference in the number of relevant features attended to between conditions. The main effect of diagnosis was not significant \( F(1,32)=2.05, p=.16 \), revealing that diagnostic groups did not differ in the overall number of features attended to. In addition, the interaction effect of diagnosis and condition was not significant, \( F(1,32)=1.51, p=.23 \), revealing that individuals with ASD did not differ from individuals with typical development in the number of features they attended to between conditions.

When examining all eye gaze results together we see a similar pattern across all areas though this pattern is significant for some measures of eye gaze but not for others. However, the medium effect sizes suggest that true diagnostic differences may emerge with increased sample size to increase statistical power. When there was no visual cue presented, individuals ASD spent less time attending to AOIs both in their overall attention (fixation duration), shifting between and within AOIs (number of fixations), and exploring the features of the animal (number of features attended to) compared to individuals with typical development when there is no visual
cue. With the addition of the visual cues, individuals with ASD and individuals with typical development do not differ in the patterns of gaze behavior.

*Relationship between Eye Gaze and Prototype Effect*

We also examined the relationship between eye-gaze and the prototype effect in order to understand how attention may affect categorization. In the NVC condition, neither the group with typical development nor groups with ASD showed a significant relationship between eye gaze and the prototype effect (See Table 4). On the other hand, in the VC condition, individuals with ASD showed a positive correlation between the prototype effect and both the proportion of fixation duration on AOIs, \( r(16) = .54, p = .02 \), and proportion of fixations made to the AOIs, \( r(16) = .47, p = .05 \). Interestingly, this significant relationship was not seen in the typically developing group when examining the relationship between the prototype effect and the proportion of fixation duration of AOIs, \( r(14) = .34, p = .20 \), and the proportion of fixation made on the AOIs, \( r(14) = .26, p = .33 \). While not significant, correlations in the group with typical development showed a similar pattern. These results indicate that higher proportion of time spent fixating on AOIs is related to higher prototype effect scores, particularly in the ASD group.

*Change in Gaze Behavior*

We were interested in how visual attention changed between the NVC and the VC condition and whether this change was related to prototype learning. In order to examine this relationship, we calculated four change scores: the prototype effect, the proportion of fixation time on AOIs, the proportion of frequency of fixation, and the number of features attended to between the VC and NVC condition. A higher prototype change score indicates a higher prototype score in the VC condition. A higher fixation time change score indicates a higher proportion of looking time to AOIs in the VC condition. A higher frequency of fixation score
indicates a higher proportion of fixations to AOIs in the VC condition. Lastly, a higher number of features attended to indicates that more AOIs were attended to in the VC condition. In the ASD group, there was a significant positive relationship between the change in the proportion of fixation time on the AOIs and change in the prototype effect, \( r(16) = .56, p = .02 \) indicating that individuals that showed increased looking at the relevant features in the VC condition also showed increased prototype learning. In the group with typical development, this relationship was not significant, \( r(14) = .20, p = .46 \), indicating that there was no clear relationship between the change in prototype effect and the change in time spent looking at AOIs (see Figure 3). When examining the change in proportion of fixations on AOIs, the ASD group showed a positive relationship, \( r(16) = .41, p = .09 \) indicating that when participants spent more time looking shifting their gaze in the AOIs, there was also an increase in their ability to form a prototype. In contrast, individuals with typical development did not show the same pattern, \( r(14) = .14, p = .60 \) (see Figure 4). Lastly, the change in the number of features attended to did not have significant relationship to the change in prototype effect for either diagnostic group (Typical: \( r(14) = -.30, p = .26 \); ASD: \( r(16) = .26, p = .29 \)). Overall these results indicate that when individuals with ASD spent more time attending to or shifting between AOIs they showed increased prototype learning. For those individuals with ASD who showed increased attention in the VC condition compared to NVC, they also showed an increase in the prototype effect.

**Discussion**

In the current study, we examined the role of attention allocation in prototype learning in individuals with ASD. Specifically, the present study examined 1) whether individuals with ASD show atypical attention during a prototype learning task and (2) whether they are able to better
perform in a prototype task with the addition of a visual cue that specifically allocates attention to relevant features.

Results indicated that both children with ASD and children with typical development (matched on age and IQ) showed prototype learning. However, there was some suggestion that children with ASD may have less robust prototype learning than children with typical development. Given the medium-effect size ($d=.51$) for this difference, it is likely that an increased sample size may reflect significant group differences. The current study included individuals with average or higher intelligence and adds to a growing literature suggesting that more obvious impairments are present in individuals with lower mental age or lower IQ (Gastgeb, 2012; Klinger & Dawson, 2001; Klinger et al., 2007) with less subtle impairments observed in those with higher mental age or higher IQ (Molesworth et al., 2005; Molesworth et al., 2008, Vladusich et al., 2010). Indeed, in the present study, verbal ability was positively and significantly correlated with prototype learning in individuals with ASD when there was no additional visual cue suggesting some type of effortful processing influencing prototype learning. This medium correlation was significant in the ASD group suggesting that there is a reliance on cognitive or verbal ability to form a prototype, an otherwise implicit learning task. This increased verbal ability and increased abstraction skills both suggest that individuals with ASD may be able to “bootstrap” their way through prototype learning tasks by compensating with verbal reasoning skills as suggested by the present study and previous literature (Klinger et al., 2007).

This study also adds to the growing literature suggesting that impairments (both subtle and more robust) are found on tasks that require more abstract learning. Studies that find no evidence of impairment tend to use more explicit methodologies. For example, in Vladusich et al. (2010), the study included an extensive training phase in which participants were provided corrective
feedback. In studies by Molesworth and colleagues (2005, 2008), animals had more obvious features with more clear variation in those features. As a result, individuals in these studies may have been able to more easily memorize or explicitly learn a prototype rather than implicitly abstract a prototype. The present study more closely replicated the automatic processes that occur in everyday life when forming a prototype.

This study also examined the relation between visual attention and prototype learning in ASD. In general, individuals with ASD spent less time examining and shifting between the relevant features when there was no cue compared to individuals with typical development. This is consistent with previous literature documenting “sticky attention” in ASD (Landry & Bryson, 2004). In the present study, individuals with ASD showed fewer fixations around the relevant features of the animal, thus their examination of the stimuli is fundamentally different than individuals with typical development. To determine if there is impairment in attention that influences prototype formation in ASD, we added a visual cue to see if individuals with ASD were better able to form a prototype when their attention was oriented to relevant features that defined the animal category.

When a visual cue to the relevant features was added, individuals with ASD and typical development did not differ on a group level. Overall, individuals with ASD did not show significantly improved prototype learning when there was an added visual cue compared to when there was no added cue. While not significant, the pattern of results raised concerns about whether individuals with typical development perform more poorly with a visual cue, perhaps because providing a specific method of learning interfered with more automatic or implicit processing that may have been employed previously. The fact that individuals with typical development did not show a relation between verbal ability and prototype learning in the NVC
condition suggests that they were not using explicit processes to reason their way through the task. Thus, providing an explicit cue may lead to a decrease in their ability to complete the task. More research is needed to explore this pattern in individuals with typical development.

While there were no group difference with regards to prototype learning and the use of a visual cue, some evidence of individual differences emerged. Preliminary analyses examining the change in gaze behavior and prototype effect between conditions suggest that individuals that attended more to the relevant features in the cuing condition also performed better on the prototype task. This suggests that attention allocation to the relevant features may allow for a more well-defined prototype in both children with ASD and typical development. Anecdotally, individuals with ASD that initially developed a poorly-defined prototype improved in their prototype learning with the addition of a visual cue.

Overall, results suggest a relationship between prototype learning and attention such that when visual cues are added to orient attention, prototype learning improves for some individuals with ASD. However, other underlying cognitive processes must influence prototype learning in ASD as the allocation of attention did not change for all individuals with the addition of a visual cue.

These results have some implications for clinical interventions. If indeed the ability to consistently form a well-defined prototype is related to an individual’s ability to orient their attention to relevant features. Interventions, such as Structured TEACCHing (Mesibov, Shea, & Schopler, 2004) that use visual structure and cues to highlight important environmental information may be effective in improving category learning. For example, visual support within an environment can help one categorize such as placing pictures of similarly objects in their desired location on a shelf (e.g. picture of books on one shelf, pictures of DVDs on another,
pictures of VHS on another, etc). This visual support provides explicit cues that allow an individual to more easily categorize objects.

**Limitations and Future Directions**

While this study provides important information on prototype formation in ASD, future studies need to continue to examine the use of a visual cue to improve category or prototype learning in individuals with ASD, particularly in those with more limited verbal abilities. When conducting the study with individual participants, children who did not form a prototype initially (i.e. endorsed the new and prototype animals equally) did not show an improvement with the addition of a visual cue. However, those children with ASD that formed a poorly defined prototype or were inconsistent without a visual cue were able to form a more well-defined prototype with the addition of a visual cue. Given these qualitative observations, future studies need to examine children with inconsistent prototype learning initially but exhibit emerging skills in this area in order to gain a more complete understanding of how a visual cue is used by children with ASD when learning prototypes. In interventions, a visual cue may allow this emerging skill to be mastered more quickly than expected. Previous studies suggest that individuals with ASD and higher verbal ability use an additional effortful process that allows them to perform better on a prototype task (Klinger et al., 2007). Participants with ASD in this study were high-functioning with an average IQ of 114 and showed a small improvement in prototype learning with the visual cue. This improvement in learning could be even greater in a sample where the average IQ or verbal ability is lower as there will be less reliance on verbal ability to complete the task initially.

A recent study by Jones and Klin (2013) found that infants that were later diagnosed with ASD had different gaze patterns towards faces between 2-6 months of age compared to those
that did not receive an ASD diagnosis suggesting that impairments or differences in attention to faces are present early in life in ASD. Thus, it may be interesting to examine the relationship between attention allocation and prototype learning in infants to better clarify the interaction between these early cognitive skills in ASD. Additionally, the use of facial prototype task may further inform our understanding of whether prototype learning is similarly impaired in social and non-social stimuli.

Although this study adds to the current research on prototype formation and gaze behavior in individuals with ASD, there are several limitations. One limitation is the small sample size in both groups resulting in underpowered analyses, which affected the interpretability of results. Additionally, the present data analysis only examines gaze behavior during the test trials in the study. Future directions include a full analysis of gaze behavior during the familiarization trials in order to examine whether individuals use the visual cue when it is initially presented and thus show a difference in their allocation of attention between the two conditions. Another limitation in that this study sampled only individuals between 8-14 years with average or above average cognitive abilities (i.e. high-functioning). Many individuals were successful on the prototype task without a cue. Given the relation between verbal ability and prototype learning in participants with ASD, it is likely they may have been able to “bootstrap” their ability to complete this task using verbal reasoning. This hypothesis is supported by the lack of correlation between verbal ability and prototype learning when another explicit strategy was provided (e.g., a visual cue). In future studies, younger children with ASD or more limited verbal ability that may not form a strong prototype initially should be tested to understand the change in their prototype formation with a visual cue.
<table>
<thead>
<tr>
<th></th>
<th>Typical</th>
<th>ASD</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 16)</td>
<td>(n = 18)</td>
<td></td>
</tr>
<tr>
<td>Chronological Age (years)</td>
<td>10.53 (1.84)</td>
<td>11.15 (1.79)</td>
<td>.34</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>15</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1</td>
<td>0</td>
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</tr>
<tr>
<td>WASI</td>
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<td></td>
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</tr>
<tr>
<td>Verbal IQ</td>
<td>115.13 (6.55)</td>
<td>111.50 (11.33)</td>
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<tr>
<td>Performance IQ</td>
<td>114.81 (10.88)</td>
<td>113.83 (13.52)</td>
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<tr>
<td>Full Scale IQ</td>
<td>116.94 (8.19)</td>
<td>114.22 (11.22)</td>
<td>.43</td>
</tr>
<tr>
<td>SRS Total T-Score</td>
<td>42.43 (5.32)</td>
<td>74.38 (9.33)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>
Table 2
Stimuli Responses: Mean (standard deviation) and significance levels of t-test comparing the recognition responses to animals within each condition between diagnostic groups (p)

<table>
<thead>
<tr>
<th></th>
<th>Typical (n = 16)</th>
<th>ASD (n = 18)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NVC</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Old</td>
<td>63% (20%)</td>
<td>67% (23%)</td>
</tr>
<tr>
<td>New</td>
<td>45% (18)</td>
<td>55% (28)</td>
</tr>
<tr>
<td>Prototype</td>
<td>92% (13)</td>
<td>89% (13)</td>
</tr>
<tr>
<td>Proto-New (Prototype effect)</td>
<td>47% (22)</td>
<td>34% (28)</td>
</tr>
<tr>
<td><strong>VC</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Old</td>
<td>56% (24)</td>
<td>64% (25)</td>
</tr>
<tr>
<td>New</td>
<td>48% (21)</td>
<td>52% (31)</td>
</tr>
<tr>
<td>Prototype</td>
<td>88% (13)</td>
<td>90% (12)</td>
</tr>
<tr>
<td>Proto-New (Prototype effect)</td>
<td>40% (27)</td>
<td>38% (27)</td>
</tr>
</tbody>
</table>
Table 3

Eye-tracking Responses: Mean (standard deviation) and significance levels of t-test comparing the recognition responses to animals within each condition between diagnostic groups (p)

<table>
<thead>
<tr>
<th></th>
<th>Typical (n = 16)</th>
<th>ASD (n = 18)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NVC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of Fixation Duration on AOIs</td>
<td>66% (10)</td>
<td>60% (10)</td>
<td>.06</td>
</tr>
<tr>
<td>Proportion of Fixations on AOIs</td>
<td>64% (11)</td>
<td>57% (8)</td>
<td>.04</td>
</tr>
<tr>
<td>Number of Features Fixated</td>
<td>2.29 features (.51)</td>
<td>2.01 features (.37)</td>
<td>.09</td>
</tr>
<tr>
<td><strong>VC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of Fixation Duration on AOIs</td>
<td>64% (9)</td>
<td>64% (11)</td>
<td>.93</td>
</tr>
<tr>
<td>Proportion of Fixations on AOIs</td>
<td>62% (7)</td>
<td>58% (8)</td>
<td>.23</td>
</tr>
<tr>
<td>Number of Features Fixated</td>
<td>2.06 features (.34)</td>
<td>1.98 features (.45)</td>
<td>.56</td>
</tr>
</tbody>
</table>
Table 4
Eye-tracking Correlations: Correlations (p-values) in each group in each condition for eye-tracking measures with the prototype effect

<table>
<thead>
<tr>
<th></th>
<th>Typical (n = 16)</th>
<th>ASD (n = 18)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NVC</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of Fixation Duration on AOIs</td>
<td>.16 (.56)</td>
<td>.12 (.62)</td>
</tr>
<tr>
<td>Proportion of Fixations on AOIs</td>
<td>.13 (.64)</td>
<td>.08 (.76)</td>
</tr>
<tr>
<td>Number of Features Fixated on</td>
<td>-.18 (.52)</td>
<td>.03 (.91)</td>
</tr>
<tr>
<td><strong>VC</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of Fixation Duration on AOIs</td>
<td>.34 (.20)</td>
<td>.54 (.02)*</td>
</tr>
<tr>
<td>Proportion of Fixations on AOIs</td>
<td>.26 (.33)</td>
<td>.47 (.05)*</td>
</tr>
<tr>
<td>Number of Features Fixated on</td>
<td>.52 (.04)*</td>
<td>.27 (.28)</td>
</tr>
</tbody>
</table>
Figure 1: Sample stimuli for the prototype task: eight familiarization stimuli and the prototype for the “MIP” animal family.
Figure 2: A sample familiarization trial for the “DAK” animal family during the visual cue (VC) condition.
Figure 3: 
Relation between the change in proportion of fixation duration on AOIs in test trials and the change in the prototype effect scores between conditions.
Figure 4:

Relation between the change in proportion of AOI fixations in test trials and the change in the prototype effect scores between conditions.


