CATEGORY FORMATION IN AUTISM: CAN INDIVIDUALS WITH AUTISM ABSTRACT SOCIAL AND NON-SOCIAL VISUAL PROTOTYPES?

by

Holly Zajac Gastgeb

B.S., Allegheny College, 1999

M.S., University of Pittsburgh, 2005

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This dissertation was presented

by

Holly Zajac Gastgeb

It was defended on

August 11, 2010

and approved by

Susan Campbell, Ph.D., Professor, Department of Psychology

Jana Iverson, Ph.D., Associate Professor, Department of Psychology

Carl Johnson, Ph.D., Associate Professor, Department of Psychology in Education

Beatriz Luna, Ph.D., Associate Professor, Departments of Psychiatry and Psychology

Dissertation Advisor: Mark S. Strauss, Ph.D., Associate Professor, Department of Psychology

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There is a growing amount of evidence suggesting that individuals with autism have difficulty with categorization. One basic cognitive ability that is necessary for categorization and may underlie difficulties with categorization is the ability to abstract and represent categorical information with a central representation or prototype. The current study examined prototype formation abilities in individuals with autism with social (faces) and non-social (dot patterns) stimuli using behavioral methodologies and eye-tracking in high functioning adults with autism and matched controls. Individuals with autism were found to have difficulty forming prototypes of both faces and dot patterns. Relationships were found between performance on the prototype tasks and measures of intelligence, symptoms of autism, and measures of low-level perceptual functioning in the individuals with autism. The eye-tracking data did not reveal any between group differences in the general pattern of attention to the faces or dot patterns during the familiarization period indicating that the difficulties with prototype formation were not due to attentional factors. The results of the current study are consistent with previous studies that have found a deficit in prototype formation and indicate that these deficits exist with both familiar social stimuli such as faces and novel non-social stimuli such as dot patterns.

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PREFACE

I would first like to thank the Autism Center of Excellence for assisting in the recruitment of participants and in the administration of various tests for my dissertation. I would like to thank my graduate student labmates Catherine Best, Keiran Rump, Desiree Wilkinson, and Sarah Hannigen, lab directors Eva Dundas, Sara Green, and Kao-Wei Chua, and the many directed research and work study students in my lab who spent precious hours assisting in data collection, AOI drawing, and data exporting. I would also like to thank all of my labmates for the wonderful emotional and social support that they have given me over the many years of graduate school. I am especially grateful for the help and support that I received over the past year as I was on internship and finishing my dissertation. I have many fond memories of times with all of you that will stay with me forever.

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1.0 INTRODUCTION

Autism, a pervasive developmental disorder with onset before age three, is characterized by qualitative impairments in social interaction and communication and repetitive stereotyped patterns of behavior, interests, and activities (American Psychiatric Association, 2000). As one of a set of disorders called autism spectrum disorders, autism shares similar impairments with Asperger's disorder and pervasive developmental disorder not otherwise specified (PDD-NOS), but at a greater level of severity. Recently, autism spectrum disorders have been a popular subject of research and have received a significant amount of attention in the popular media due to an alarming rise in prevalence world-wide. According to the most recent reports from the Centers for Disease Control, one in every 110 children in the United States develops an autism spectrum disorder (Centers for Disease Control and Prevention, 2007). As a result, it is imperative that researchers gain a better understanding of the underlying deficits in autism.

To date, much research on autism has focused on social deficits, because they are both necessary and unique to the diagnosis. However, there is a growing literature suggesting that individuals with autism also have significant information processing and cognitive deficits (e.g., Frith & Happé, 1994; Mottron & Belleville, 1993; Ozonoff, 1997; Plaisted, O'Riordan, & Baron-Cohen, 1998), and indeed some believe that these cognitive processing differences should be considered as a part of the diagnostic criteria for autism (Mottron, Dawson, Soulières, Hubert, & Burack, 2006). Several theories have been proposed to explain cognitive deficits in individuals with autism including executive functioning (e.g., Ozonoff, 1997), weak central coherence (e.g., Frith & Happé, 1994), and theory of mind (e.g., Baron-Cohen, Leslie, & Frith, 1985). Although these theories have a number of strengths that aid in understanding the syndrome of autism, they also share a number of weaknesses.

First, all three theories consist of broad constructs that are difficult to operationally define. It is difficult to know exactly what is meant by "theory of mind", "executive functioning", or "central coherence", because the definitions tend to vary depending on the researcher, the research question of interest, and the range of measurements that are used to address this question. Second, the measurement tools and experimental tests that are used to study each of these theories are broad, imprecise, and artificial. Experimental tests of all three theories often have components that tap into aspects of language, attention, memory, and other cognitive abilities. Third, tests of weak central coherence and theory of mind require executive functioning, tests of theory of mind and executive functioning may be approached with a weak central coherence processing style, and tests of executive functioning and weak central coherence may require people to have a theory of mind in order to understand what they should be doing. Thus, these abilities may be interrelated and tests have not yet been designed that can precisely measure the abilities or deficits proposed by one theory.

More recently, researchers have started to move away from these broad theories and are beginning to study other more specific aspects of cognitive and information processing that may be different or deficient in autism. One aspect of information processing that is receiving more attention in research with individuals with autism is categorization. Categorization is critically important, and it is evident that within the first year of life infants begin to form categories (e.g., Lewis & Strauss, 1986; Quinn & Oates, 2004). Categorization reduces demands on memory and allows individuals to focus on important aspects of objects while ignoring irrelevant details. It also allows children to understand what others are saying and to learn language. There is a growing amount of evidence suggesting that individuals with autism have difficulty with some aspects of object categorization and engage in different categorization processes than do typically developing individuals (e.g., Gastgeb, Strauss, & Minshew, 2006; Klinger & Dawson, 1995; Plaisted, 2000). It is also well-known that individuals with autism have deficits in the categorization and perception of facial information including categorization of gender (e.g., Behrmann et al., 2006; Best, Minshew, & Strauss, 2010; Deruelle, Rondan, Gepner, & Tardif, 2004), facial expression, (e.g., Celani, Battacchi, & Arcidiacono, 1999; Rump, Giovannelli, Minshew, & Strauss, 2009), face recognition (e.g., Best, Strauss, Newell, & Minshew, in prep; Klin, Sparrow, de Bildt, Cicchetti, Cohen, & Volkmar, 1999; Lahaie, Mottron, Arguin, Berthiaume, Jemel, & Saumier, 2006) and the perception of facial distinctiveness (e.g., Best, Strauss, Newell, & Minshew, 2005). The question that remains is whether there is a specific process that may underlie the difficulties that individuals with autism have with categorization of both objects and faces.

1.1 PROTYPE FORMATION IN TYPICAL POPULATIONS

One basic cognitive ability that is necessary for the categorization of objects and faces and may underlie the processing differences and deficits with both is the ability to abstract and represent categorical information with a central representation or prototype. A prototype is an average representation of past information that depicts the average of the variations within a given category that is stored in the brain. There has been a debate in the literature as to whether objects are stored as exemplars in a multidimensional space (Nosofsky & Kantner, 2006) or around an abstracted prototype of a category (Smith, 2002; Smith, Redford, Gent, & Washburn, 2005). Although this debate has yet to be resolved, many believe that it is likely that people can do either and that which process is used depends on available aspects such as the type and amount of information about a category and the amount of experience that one has with a given category (Kéri, 2003; Murphy, 2002). The ability to form a prototype is a critical skill for category learning, because it decreases memory load and allows individuals to store an average representation of items that they have experienced rather than needing to store every item in memory.

Prototype formation is particularly important for face perception and recognition. Valentine (1991) suggests that exemplars and prototypical information about faces are stored in a multidimensional space called the "face space" that is formed through experience with faces. He proposed a multi-dimensional framework in which faces are stored in an *n*-dimensional space representing all possible features used to encode a face, including both featural and configural information in addition to information used to discriminate faces (e.g., age, gender, and race). The center of this multi-dimensional framework represents the central tendency of all facial information (prototype), and the distribution of facial features and facial information is normally distributed around this central tendency. Valentine's (1991) face-space theory provides an explanation and framework for many face perception and recognition effects. This includes the recognition advantage for distinctive faces and caricatures (e.g., Best & Strauss, 2007; Best, Strauss, Newell, Gastgeb, and Costello, 2004; Devine & Malpass, 1985; Goldstein & Chance, 1980; Humphreys, 2003; Rhodes, Brennan, & Carey, 1987), the classification advantage of gender-typical faces in gender classification tasks (e.g., O'Toole et al., 1998), and the preference for attractive faces over unattractive faces (e.g., Rubenstein, Kalakanis, & Langlois, 1999).

The ability to form a prototype of faces and objects is a specific process that is present in infants (Quinn, 1987; Ramsey, Langlois, & Marti, 2005; Younger & Gotlieb, 1988) from as early as three months of age (Bomba & Siqueland, 1983). Researchers found that when infants were given a choice between a never seen prototype (face comprised of averaged features) and either a previously seen face or a novel face, infants looked less at the prototype face (Rubenstein, et al., 1999; Strauss, 1979). This indicates that the infants considered both the previously seen face and the novel face as more novel than the prototype. Because the prototype was never seen, the infants must have abstracted the prototype by viewing the variations of the faces that were presented to them. Other researchers have found similar evidence for prototype formation of object categories (Younger, 1985, 1990) and dot patterns (Bomba & Siqueland, 1983; Younger & Gotlieb, 1988) in infants. Thus, it appears that young infants can form a prototype of a variety of information from a very young age.

Evidence for the formation of prototypes in children and adults comes from studies on the prototype effect, the tendency to falsely remember a prototype as previously seen or experienced even though it is comprised of a combination of features that were either never seen at all or seen infrequently but never in that combination. A classic study by Posner and Keele (1968) found that when adults are trained on dot patterns that vary and are then later tested on a variety of dot patterns, they tend to falsely remember the unseen prototype and consider it to be as familiar as dot patterns that were previously seen. This effect has been replicated using a wide range of stimuli including dots (Kéri, Kálmán, Kelemen, Benedek, & Janka, 2001; Knowlton & Squire, 1993; Zaki & Nosofsky, 2004), abstract forms (Homa, Goldhart, Burruel-Homa, & Smith, 1993), and faces (Gastgeb, Rump, Best, Minshew, & Strauss, 2009; Reed, 1972) in a wide variety of populations including typically developing children (Hayes & Taplin, 1993b), children with mild learning disability (Hayes & Taplin, 1993a), adults with Alzheimer's disease (Kéri, Kálmán, Rapcsak, Antal, Benedek, & Janka, 1999; Kéri, Kálmán, et al., 2001), adults with schizophrenia (Kéri, Kelemen, Benedek, & Janka, 2001), and individuals with mild mental retardation (Hayes & Conway, 2000). Researchers have also found a relationship between the similarity of a pattern/object to the prototype of a certain category and the likelihood of it being recognized as a member of that category (Cabeza, Bruce, Kato, & Oda, 1999; Knowlton & Squire, 1993; Solso & McCarthy, 1981), with exemplars of high similarity (or small amounts of distortion from the prototype in the case of dots) resulting in greater recognition than low similarity (or high amounts of distortion from the prototype in the case of dots).

While the formation of a prototype is a basic cognitive ability that is present in infancy and throughout adulthood, it is also a very complex high-level cognitive process. In order to form a prototype of a category, an individual needs to learn what aspects of the objects vary, how they vary, and the boundaries of this variation. They need to be able to abstract the average and variability of these aspects and form them into a multidimensional composite (the prototype). Prototypes also impact top down processes such as comparisons of new exemplars to the prototype which can then influence processes such as the discrimination of subtle differences that is necessary for categorization. These types of processes are most important as people develop expertise with a given category and begin to develop more subordinate categories which require more subtle discriminations.

Research by Tanaka and Taylor (1991) found that as people gain more expertise with a category such as dogs, they are able to do finer, more subtle levels of discrimination and with enough experience process these subordinate categories in the same way as non-experts process basic level categories. Thus, dog experts' prototypes have been updated to include all of the subtle features that differentiate within a breed of dog and future exposures to dog exemplars will be affected by comparisons to these prototypes. Therefore, the formation of a prototype can affect categorization in a multitude of ways from decreasing demands on memory to influencing what subtle differences are even perceived by an individual. If individuals with autism are unable to form a prototype or do so in a different way, this may affect their ability to categorize both objects and faces which in turn could lead to the difficulties in socialization and communication that are present in autism.

1.2 CATEGORIZATION IN INDIVIDUALS WITH AUTISM

Results of studies conducted to determine if there are categorization deficits in individuals with autism have been mixed. Early studies concluded that individuals with autism are able to form categories successfully. These studies, however, used categories that had simple definitive features such as color or size and did not examine whether individuals with autism *process* category information in the same manner as typically developing individuals, especially when the categories are more complex (Tager-Flusberg, 1985; Ungerer & Sigman, 1987). It is possible that, while individuals with autism can successfully categorize on the basis of simple definitive features, they may have difficulty categorizing when categorization is based on more complex or less perceptually apparent features (Klinger & Dawson, 1995; Plaisted, 2000). Another possible explanation for the mixed findings is that most studies of categorization have failed to control for typicality of the stimuli. It is possible that while individuals with autism may be able to categorize typical exemplars, less typical exemplars may pose more difficulty. As category exemplars become less typical, criterial features also become less apparent and decision processes become more difficult. Thus, studies using only typical exemplars of a category may not indicate deficits in these individuals. Studies using atypical exemplars, however, may show categorization deficits as the task becomes more difficult.

Several studies support the notion that individuals with autism can and do form categories, but they do so in a way that is different from typically developing individuals. A few studies have provided evidence that individuals with autism do not group words into categories in order to aid in memorization (Hermelin & O'Connor, 1970; Minshew, Goldstein, Muenz, & Payton, 1992). Hermelin and O'Connor (1970) compared children with autism to those showing typical development and delayed development and found that children with autism did not memorize words by grouping them into conceptual categories relative to children with typical or delayed development. Minshew et al. (1992) found that individuals with autism, unlike typically developing individuals, did not use categorical information as a strategy to improve memory on the California Verbal Learning Test. In both of these studies, the individuals with autism were able to remember as many items as controls, suggesting that they did not have an impairment in rote-memory but were not using organizing strategies of categorization to improve their memories.

Minshew, Meyer, and Goldstein (2002) conducted a study that examined the performance of high-functioning individuals with autism, compared to controls, on concept identification versus concept formation tasks. These tasks differ in that, in concept identification tasks, the concepts are not formed by the person but are inherent in the test materials. In contrast, in concept formation tasks the concepts have to be self-generated, and the person is required to generate the rules in order to group the stimuli. The researchers found that high-functioning individuals with autism had a deficit only in concept formation and that this deficit resulted in cognitive inflexibility and the inability to spontaneously form ways in which to organize information. These results support the notion that individuals with autism process and group information in a rule-based manner and are deficient when the task requires that concepts be abstracted from complex information.

A study conducted by Plaisted et al. (1998) provides additional evidence that suggests that individuals with autism categorize and form concepts in a manner that is different from typically developing individuals. In this study, control adults were better able to discriminate familiar stimuli than novel stimuli. High-functioning adults with autism, however, were not better at discriminating familiar than novel stimuli. The authors suggested that high-functioning adults with autism process features that are common between objects poorly and, therefore, process features that are unique to an object well. If features in common between objects are processed poorly, categorization would be affected, because categorization involves the ability to determine what aspects of exemplars are common. If individuals with autism are unable to determine the commonality among items, they also may be unable to determine the commonality among situations. This could lead to an inability to use information about prior instances to inform new situations resulting in a world that is confusing and overwhelming. Poor ability to process features common to stimuli in conjunction with the ability to process features unique to a stimulus well supports the idea of the existence of different categorization processes in individuals with autism.

More recently, Gastgeb et al. (2006) performed a unique study that examined categorization processes across development from childhood to adulthood in typically developing individuals and individuals with autism. It was also the first study to consider the role of typicality or task difficulty in categorization of natural categories. The results indicated that both individuals with autism and typically developing individuals showed improvement in their categorization abilities throughout the lifespan for all levels of typicality. In fact, by the adolescent years, categorization ability and processing efficiency of typical and somewhat typical category members developed to a comparable level in both groups. In contrast, categorization processing differences were found throughout the lifespan with respect to atypical or poor category members. Indeed, adults with autism never reached the same proficiency in categorization as the control adults for the atypical category members.

The results of this study suggest that individuals with autism can readily categorize when the task involves simple and typical basic objects but have difficulty when categorization is more complex or involves less typical objects. Jolicoeur, Gluck, & Kosslyn (1984) suggest that atypical stimuli require additional *perceptual* processing in order to be categorized. Thus, it is possible that individuals with autism have difficulty with the type of additional perceptual processes that are needed to categorize atypical stimuli. For the remainder of this paper, these additional perceptual processes will be referred to as "subordinate perceptual processes", because they are equivalent to the types of processes needed for subordinate level categorization (e.g., Gauthier, Tarr, Moylan, Anderson, Skudlarski, & Gore, 2000).

To illustrate these perceptual processes, imagine an atypical piece of furniture that is longer than the typical chair but shorter than the typical couch (i.e., a loveseat). How does one decide whether this piece of furniture is a chair or not? One cannot use the simple, criterial feature of "short or not short" to decide category membership, because length does not provide enough clear information for this decision. Rather than comparing only simple features, comparisons of subordinate or atypical category members require that quantitative spatial information be considered (e.g., subtle differences in the length of a couch versus a chair).

Additionally, when categorizing atypical or subordinate exemplars, it is necessary to do a careful comparison of the exemplar to stored category members or to a prototype of the category and decide if the piece of furniture looks more like the prototype or stored exemplars of couches or chairs (Homa, Smith, & Macak, 2001). Finally, categorizing atypical and subordinate exemplars may require the comparison of multiple features and the ability to flexibly weight these features in the decision process. For example, because the length of a loveseat is at the category boundary, other features such as style, fabric, and so on may take on greater weight in the categorization decision. If individuals with autism have difficulty forming a prototype or do so differently than typically developing individuals, they would need to engage in different processes in order to categorize atypical category members and possibly even other information in their environments.

To date, no studies have explored the role that subordinate perceptual processes may play in the object categorization of individuals with autism. However, direct evidence that individuals with autism have difficulty with subordinate perceptual processes comes from the face literature. It is important to note that the corresponding terms for subordinate perceptual processes in the face literature are configural and holistic processes. Many studies have found that individuals with autism process faces more featurally or part-based rather than using more subtle quantitative comparisons (e.g., Boucher & Lewis, 1992; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Joseph & Tanaka, 2003). There is also evidence that individuals with autism are unable to abstract prototypes or average representations of faces (Gastgeb, Rump, Best, Minshew, & Strauss, 2009). Finally, a recent study (Strauss et al., in submission) on gender categorization found that, although individuals with autism were able to accurately categorize the gender of faces that were typical examples of men or women, they had difficulty (in terms of both accuracy and reaction time) with categorizing atypical exemplars of gender which requires more subtle quantitative comparisons for successful categorization. Thus, the face literature provides evidence of deficits in two of the subordinate level perceptual processes, a lack of subtle quantitative comparisons when processing faces and an inability to abstract prototypes or average features of faces.

1.3 PROTOTYPE FORMATION IN INDIVIDUALS WITH AUTISM

Temple Grandin, a high-functioning adult with autism who is well-known for her books and lectures on autism, describes what it is like to think differently than other people, “My cat or church or steeple concept is based on a series of ‘videos’ of different cats or churches that I have experienced. There is no generalized cat concept” (Grandin, 1995, p. 142). Grandin does not believe that she forms prototypes or generalized representations of the objects that she sees or learns about in the world but stores videos of each exact item that she has experienced in her memory.

Although there has been relatively little research on prototype formation in autism, there are a few studies that suggest that individuals with autism are unable to abstract a prototype or average representation of the features of an object category. Klinger and Dawson (2001) compared low-functioning children with autism, children with Down’s syndrome, and typically developing children’s abilities to use rule-based and prototype category learning. The authors found that all groups were able to categorize using a rule-based strategy when the rule was explicitly stated and when the rule was implicit, but neither the children with autism nor Down’s syndrome were able to abstract a prototype of simple animal-like categories during category learning. Additionally, individuals with autism and Down's syndrome were able to categorize the animal-like exemplars only when there was a single distinctive feature present such as "long feet." Typically developing children, however, did not exhibit any difficulties with abstracting a prototype. Plaisted (2000) discussed two unpublished studies that indicated that high-functioning adults and children with autism matched with controls on general cognitive level were also unable to form prototypes. More recently, Klinger, Klinger, and Pohlig (2006) replicated the Klinger and Dawson (2001) study using a larger number of high-functioning children ranging from 5 to 17 years of age and again found a significant difference between the control children and children with autism on a prototype formation task. As a result, the inability to form prototypes in the Klinger and Dawson (2001) study probably cannot be explained by mental retardation or general level of cognitive functioning.

In contrast, Molesworth, Bowler, and Hampton (2005) failed to find a lack of prototype formation in high functioning children with autism and Asperger's disorder. The first study on the formation of an average (or mean) prototype utilized stimuli that consisted of a combination of six features that varied on a quantitative dimension of six different values (i.e., different sizes from 1 to 6, with 1 being the smallest and 6 being the largest). The participants were familiarized with stimuli comprised of all features with size values equal to 2 or 5 and then were shown a variety of stimuli and had to decide if they had seen each stimulus before or not. The second study on formation of a modal prototype utilized stimuli that consisted of a combination of six features that varied on a qualitative dimension of five different values (i.e., different shapes from 1 to 5). The participants were familiarized with stimuli that shared three out of six features with the prototype and then again were shown a variety of stimuli that they had to decide if they had seen before or not. In both studies, the authors found that individuals with autism were able to form a prototype and exhibited a full prototype effect. This was evidenced by a false memory for an unseen prototype in both studies. The authors concluded that the result of an intact prototype effect in individuals with autism was due to methodological differences in their study such as studying a higher functioning group of children with autism, using cartoon animal stimuli, and requiring simple responses from the children.

More recently, Molesworth, Bowler, and Hampton (2008) replicated their findings and again found an intact prototype effect in high functioning children with autism and Asperger's disorder using a different test procedure. This study utilized stimuli that were created using the same criteria as the first study in their 2005 paper. Again, participants were familiarized with stimuli that were labeled "medium family resemblance" (medium FR) and were comprised of all features with size values equal to 2 or 5. During this familiarization phase, cards depicting medium FR members of two different categories (e.g., *Hov* and *Mek*) were placed in front of the participants. The participants were instructed to study these cards and all additional cards for three minutes. The experimenter then handed the cards to the participants one at a time and encouraged them to study each card and then place it face up on the pile of cards from the same category. During the test phase, the participants were shown three stimuli from one of the categories: the prototype, a new medium FR stimulus, and a low FR stimulus (a stimulus comprised of all features with size values equal to 1 or 6). The participants were instructed to look at the choices and to choose the best member of the category (e.g., the best *Hov*). They were then presented a test trial for the other familiarization category. The entire familiarization and test procedure was repeated two more times for a total for six categories. The authors found that individuals with autism showed a prototype effect with the prototype being chosen as the best member of the category more than the medium FR stimuli which were chosen more than the low FR stimuli. There were no differences between the autism group and the control group for the low FR, medium FR, or prototype stimuli. It was again concluded that the result of an intact prototype effect in individuals with autism was due to studying a higher functioning group of children with autism.

However, it is possible that the "intact prototype formation" results found by Molesworth et al. (2005, 2008) were due to other reasons that were not discussed. First, the autism groups included both high-functioning children with autism and children with Asperger's disorder. While there has not been much evidence that these two disorders on the autism spectrum are qualitatively different in terms of neuropsychological functioning, it is unknown whether their cognitive processes (such as the ability to form a prototype) are the same. In fact, a recent study by Mazefsky and Oswald (2007) found a difference in emotion perception between individuals with Asperger's disorder and those with high-functioning autism. In this study, individuals with Asperger's disorder performed equally well as typically developing individuals, but individuals with autism performed significantly worse than both groups on measures of emotion perception. This suggests that it may be important to examine these groups separately when studying other types of categorization. Second, it is unclear whether individuals with autism formed a prototype in the studies on the formation of an average or mean prototype (study 1 in the 2005 paper and the 2008 replication), or just determined what features were varying. The features that were varied were fairly obvious and the differences between the values were not very subtle. Thus, it is possible that the individuals with autism formed an average of each feature or possibly just one feature but did not actually form prototypes of the learned categories. Finally, it is also unclear whether individuals with autism formed a prototype in the second study in the 2005 paper, the study on the formation of a modal prototype. In this case, the features that varied were quantitative (shape), and therefore it is possible that the individuals with autism falsely remembered the prototype because they remembered the features that had a value of 1 (the values that made up the prototype) which were also shown more frequently than the other values during the familiarization phase (since all familiarization stimuli shared three out of six features with the prototype). Thus, the individuals with autism may have shown a prototype effect due to memorization of specific features rather than the formation of a prototype.

Only one study to date has examined the ability of individuals with autism to form a prototype of faces. Gastgeb, Rump, Best, Minshew, and Strauss (2009) tested high-functioning children and adults with autism and matched controls on a face prototype task patterned after a study originally conducted on both adults and 10-month-old infants (Strauss, 1979). Participants were presented with 14 schematic drawings of faces varying on four facial dimensions – eye separation, nose width, nose placement height, and head length. There were three values of each dimension (e.g., wide, narrow, and average nose widths). Across the 14 faces, participants saw the two extreme values of each feature 12 times and the average value only twice. Participants were then presented with two test faces, the prototype (which contained the average value on all dimensions) and a face consisting of values that were more frequently experienced, and asked to say which face looked more familiar Results indicated that 78% of the adults in the control group chose the prototype as more familiar than the face comprised of features that were more frequently seen while only 55% of the adults with autism chose the prototype. For the child groups, 69% of the typically developing children chose the prototype as more familiar while only 48% of the children with autism chose the prototype (chance). These results add to those of Klinger and colleagues, suggesting that individuals with autism also have difficulty forming mean prototypes of facial information. This study suggests that individuals with autism do not automatically abstract prototypical information during an exposure paradigm with passive face viewing.

Gastgeb et al. (2009) provided a more stringent test of mean prototype formation than previous studies for several reasons. First, Gastgeb and colleagues used faces, a natural category exhibiting subtle featural variations that are quantitative in nature. Second, stimuli were designed using subtle variations of continuous facial attributes that were combined to ensure participants saw mean prototype values less frequently than mode prototype values. Thus, pure memorization of features would have resulted in individuals choosing the mode prototype more often which did not occur. It is possible that the results reflected chance behavior; however, the control group showed clear evidence of selecting the mean prototype at levels greater than chance. It may also be argued that the results of the autism group were not due to a difference in mean prototype formation but rather a general face perception deficit from reduced attention to faces resulting in less experience with faces. Since infants have minimal experience with faces and can abstract mean prototypes, this possibility is less likely but cannot be ruled out.

1.4 CURRENT STUDY

The results from the few prototype formation studies that have been published thus far suggest that individuals with autism engage in different categorization processes than typically developing individuals and that these differences may be very basic and early developing (Klinger & Dawson, 1995; Strauss, Newell, & Best, 2003). An inability to abstract prototypes in individuals with autism is surprising due to the fact that studies on prototype formation in children have established that infants are able to abstract prototypes (Strauss, 1979; Younger, 1985, 1990). An early deficit in the mechanisms used to form prototypes would result in infants having difficulty decreasing the amount of information in a complex environment and easily becoming overstimulated by sensory information. Given the complexity of social information, infants may find it more adaptive to tune out social information rather than pay attention to it. Thus, previous results concerning a potential deficit in prototype formation need to be replicated in more samples of individuals with autism using a variety of stimuli in order to better understand prototype formation abilities in individuals with autism.

Also, studies to date are unable to provide any information about what the individuals with autism and typically developing individuals are attending to or looking at when they are forming prototypes or categories. Individuals with autism may spend less time in general looking at or attending to the training/familiarization stimuli. Another possibility is that they may appear to be looking at the stimuli but may actually be looking at the corner or other irrelevant parts of the stimulus where there is no relevant information about the category. Individuals with autism may also attend to specific parts of the stimulus rather than to the whole stimulus. Any or all of the above information may provide an explanation for *why* individuals with autism have difficulty forming prototypes or categories. Thus, it is important for researchers to use technology such as eye-tracking in order to examine what areas of the face/object are being examined during the familiarization or training phases. By doing so, researchers not only determine *if* individuals with autism have difficulty forming prototypes or categories but also *why* they have difficulty.

Finally, no studies on prototype formation in autism to date have examined whether individuals with autism evidence difficulty in prototype formation in both social and non-social domains. Researchers have studied formation of prototypes using faces or cartoon animals, but have not examined prototype formation for more than one type of stimulus in the same participants. It is possible that the difficulties that individuals with autism have with prototype formation are domain-general and that all domains (e.g., social and non-social) are equally affected. It is also possible that individuals with autism have difficulty forming prototypes across multiple domains but that the deficit is more prominent in the social domain due to the increased amount of variability.

The current set of studies aimed to provide answers to the above questions by first replicating the findings of previous prototype studies in another group of high-functioning adults with autism. Both a face prototype study (Experiment 1) and a dot prototype study (Experiment 2) were included in order to determine whether individuals with autism have difficulty with prototype formation across both social (faces) and non-social (dots) domains. The participants' eye movements were recorded in order to gather vital information about which areas of the faces or dot patterns individuals with autism and control individuals fixated on when looking at the familiarization trials (learning).

1.4.1 Specific Aims

The general aim of Experiment 1 was to determine whether individuals with autism have difficulty forming a prototype of facial information. As stated earlier, it is a well known and well replicated finding that individuals with autism have deficits in face perception and recognition. Thus, it is important to know whether individuals with autism can form a prototype of a face and whether they look at all of the relevant parts of the faces that are presented (i.e., the parts that vary from one face to another). Also, the only previous study on face prototype formation in autism (Gastgeb et al., 2009) used schematic line drawings of faces rather than natural faces. The current study utilized natural faces in order to more closely replicate the facial information that is abstracted in real life categorization. Individuals with autism were familiarized with sets of faces and after each set chose which face was more familiar, the prototype face or a face comprised of features that were previously seen (mode face).

Experiment 1 had four aims:

1. To investigate whether individuals with autism experience difficulty abstracting prototypes of facial information with naturalistic faces.
2. To determine whether facial prototype formation ability is related to measures of intelligence, low-level perceptual processing, or the social, communication, and behavioral symptoms of autism.
3. To use eye-tracking technology to investigate what areas of the stimulus and/or face typically developing individuals and individuals with autism attend to or look at when forming a prototype of faces.
4. To examine individual differences in the ability to abstract prototypes in individuals with autism. For example, how variable are the abilities of individuals with autism to abstract prototypes, and is there a subset of individuals with autism who are successfully able to form a facial prototype? If so, do these individuals differ from those who are unable to successfully form a facial prototype on measures of intelligence, low-level perceptual processing, symptoms of autism, or eye-tracking measures?

The general aim of Experiment 2 was to determine whether individuals with autism have difficulty forming a prototype of non-social information which in this study was dot patterns. Dot prototype studies have been used to study prototype formation in typically developing individuals from infancy to adulthood in addition to clinical populations such as Alzheimer's disease (Kéri et al., 1999; Kéri, Kálmán, et al., 2001), schizophrenia (Kéri, Kelemen, et al., 2001) and mental retardation (Hays & Conway, 2000). This suggests that it is a good paradigm for studying prototype formation in autism. Dot patterns are also good stimuli for prototype formation studies, because the participants have no prior knowledge of or experience with categorizing dot patterns. Thus, a study of dot prototype formation provides information about the pure process of prototype formation and how individuals with autism deal with perceptual variability without any possible confounds of experience. Experiment 2 is based on a study by Kéri, Kálmán, et al. (2001). Dot stimuli that were in the same dot pattern category as the prototype were created by moving dots either a small distance from their placement in the prototype (low distortion) or a large distance from their placement in the prototype (high distortion). Dot stimuli from another dot category were also created (non-category). Individuals with autism and control individuals were familiarized with high distortions of a prototype dot pattern and then tested on their ability to correctly categorize dot patterns that were the prototype, low distortions of the prototype, new high distortions of the prototype, and non-category patterns (patterns from another dot pattern category).

Experiment 2 had four aims:

1. To investigate whether individuals with autism experience difficulty abstracting prototypes of dot pattern information
2. To determine whether dot prototype formation ability is related to measures of intelligence, low-level perceptual processing, or the social, communication, and behavioral symptoms of autism.

3. To use eye-tracking technology to investigate what areas of the stimulus and/or dot pattern typically developing individuals and individuals with autism attend to or look at when forming a prototype of dot patterns.
4. To examine individual differences in the ability to abstract dot prototypes in individuals with autism. For example, how variable are the abilities of individuals with autism to abstract dot prototypes, and is there a subset of individuals with autism who are able to successfully form a prototype of dot patterns? If so, do these individuals differ from those who are not able to successfully form a prototype of dot patterns on measures of intelligence, low-level perceptual processing, symptoms of autism, or eye-tracking measures?

1.4.2 Hypotheses

For Experiment 1, it was hypothesized that:

1. Control participants would consider the prototype faces to be more familiar than faces comprised of feature values that have been previously viewed.
2. There would be a deficit in the formation of a face prototype in individuals with autism in that they would not consider the prototype faces to be more familiar than faces comprised of feature values that have been previously viewed.
3. There would be significant group difference between the percentages of prototype faces chosen as familiar with control participants choosing the prototype faces significantly more often than the individuals with autism.

4. If a subset of individuals with autism form a prototype, these individuals would engage in different patterns of eye fixations or differ from individuals who do not form a prototype on measures of intelligence, low-level perceptual processing, or the social, communication, and behavioral symptoms of autism.
5. Control participants would show a pattern of eye fixations that involves looking at many areas of the faces including the parts of the faces that vary from one face to another during the familiarization trials.
6. Individuals with autism would show a pattern of eye fixations that involves looking at fewer or irrelevant aspects of the faces during the familiarization trials.
7. There would be no group difference in the percentage of time spent looking at the faces during the familiarization trials.

For Experiment 2, it was hypothesized that:

1. Control individuals' results would parallel those from Kéri, Kálmán, et al. (2001) in that the prototype would be correctly categorized more often than the low distortions which in turn would be categorized correctly more often than the high distortions. The non-category distortions would be categorized as members of the learned category the least often.

2. Individuals with autism would not show the same pattern of results as the control individuals and would evidence difficulty forming the dot pattern prototype. One possibility is that all individuals with autism would have difficulty abstracting a prototype which would be evidenced by relatively little difference between performance on the prototype, high distortion, and low distortion stimuli. It is also possible that the individuals with autism or a subset of individuals with autism would have some abstraction abilities but that their abilities would be more limited. This would be evidenced by successful categorization of prototype and low distortion exemplars but difficulty with categorizing high distortion exemplars that are less like the prototype.
3. There would be significant group difference between the percentages of dot patterns endorsed as category members with control participants correctly categorizing all stimuli more often than the individuals with autism.
4. If a subset of individuals with autism perform better on the dot prototype task, these individuals would engage in different patterns of eye fixations or differ from individuals who do not form a prototype or who only evidence some abstraction abilities on measures of intelligence, low-level perceptual processing, or the social, communication, and behavioral symptoms of autism.
5. Control participants would show a pattern of eye fixations that involves looking at all or most of the dots in the dot patterns during the familiarization phase.
6. Individuals with autism would look at fewer dots or fixate on certain regions of the dot patterns during the familiarization phase.

7. There would be no group difference in the percentage of time spent looking at the dot patterns during the familiarization trials.

2.0 EXPERIMENT 1: FACE PROTOTYPE

2.1 METHOD

2.1.1 Participants

Participants consisted of 20 high-functioning adult males with autism and 20 healthy control adult males recruited by the Pittsburgh Autism Center for Excellence (ACE) at the University of Pittsburgh. All participants provided written informed consent according to the guidelines of the University of Pittsburgh Medical Center Institutional Review Board and were paid for their participation in the study. Control participants were recruited through posters, newspaper advertisements, radio ads, and community television announcements. Individuals with autism were recruited through informational visits to service providers throughout the state of Pennsylvania and the surrounding states, fliers at autism meetings, advertisements in autism newsletters, and posters. No restrictions were placed on ethnicity, location of residence, or SES. Participants were recruited and matched according to the following criteria:

2.1.1.1 General Inclusion Criteria

In order to participate, all individuals were required to have full-scale and verbal IQs greater than 80 as determined by the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). They were also required to be between 17 and 50 years of age and in good medical health. The lower age limit existed in order to exclude any effects that may have been the result of continued development of skills through adolescence while the upper age limit existed in order to reduce the effects of normal aging on behavior and brain function. The IQ limit existed for two reasons. One reason is that the nature of the study required verbal comprehension abilities that may not be present in lower functioning individuals with autism. Also, studying high-functioning individuals with autism allows for the discovery of cognitive differences and potential deficits that are specific to autism and not the non-specific consequences of mental retardation.

2.1.1.2 Inclusion-Exclusion Criteria for Participants with Autism

Participants with autism were also required to: 1) meet DSM-IV-TR criteria (American Psychiatric Association, 2000) for autism on the basis of the Autism Diagnostic Interview-Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994) and the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, Goode, Heemsbergen, Jordan, Mawhood, & Schopler, 1989) with confirmation by expert clinical opinion; 2) have no evidence of underlying cause for autism on the basis of physical examination, neurologic history and examination, and chromosomal analysis; 3) be free of seizure disorder and major depression at the time of the study; and 4) have a clinically significant delay in language (exclusion of those with pervasive developmental disorder not otherwise specified and Asperger's disorder).

2.1.1.3 Inclusion- Exclusion Criteria for Control Participants

The control participants were also required to: 1) be free of neurologic disorders currently and in the past on the basis of neurologic history obtained with a questionnaire; 2) be free of psychiatric disorders currently and in the past on the basis of a semi-structured interview designed to ascertain present episode and lifetime history of psychiatric illnesses according to DSM-IV criteria (Adult Symptom Inventory-4, Gadow, Sprafkin, & Weiss, 1999); 3) have a negative family history in first degree relatives of affective and anxiety disorders or other major psychiatric disorders based on the Family History Screen (Weissman, Wickramaratne, Adams, Wolk, Verdeli, & Olfson, 2000); 4) have a negative family history in first and second degree relatives of autism or other autism spectrum disorders; 5) have no historical evidence of significant difficulty during pregnancy, labor, delivery, or immediate neonatal period or abnormal developmental milestones as determined by questionnaire; 6) have a history of school attendance and grades consistent with ability level; 7) have no evidence by history or school records of a disparity between general level of ability and academic achievement; and 8) have no history of a loss of consciousness. The exclusion of controls with a history in first degree relatives of affective disorders, anxiety disorders and autism spectrum disorders or a history of autism spectrum disorders in first and second degree relatives was aimed at excluding those with potential autism susceptibility genes, because these disorders occur more often in autism families.

2.1.1.4 Matching Criteria for Participant Groups

Control participants were matched to the autism group (same mean) on age, full scale IQ (FSIQ), verbal IQ (VIQ), performance IQ (PIQ) and gender. Initially controls were recruited broadly across the age range, and as participants with autism were recruited, the recruitment of controls was tailored to achieve matching. Table 1 summarizes the participants' demographic characteristics. No significant differences were found between the two groups on age, FSIQ, VIQ, or PIQ.

Table 1. Participants' Diagnostic and Demographic Characteristics for Experiment 1

	Autism Group (*n* = 20)		Control Group (*n* = 20)	
	M (*SD*)	(Range)	*M* (*SD*)	(Range)
CA	22.85 (6.16)	(17-39)	25.45 (6.29)	(18 – 42)
VIQ	107.40 (10.77)	(88 – 127)	111.00 (7.20)	(94 – 122)
PIQ	108.30 (13.24)	(83 – 131)	110.50 (8.96)	(93 – 125)
FSIQ	108.65 (9.17)	(92 – 128)	112.35 (7.90)	(97 – 122)

Note. CA = Chronological Age in years; VIQ = Verbal IQ; PIQ = Performance IQ; FSIQ = Full Scale IQ

2.1.2 Apparatus

Testing occurred in a quiet, dark laboratory room in a testing booth surrounded by black curtains. Each participant was seated in a modified desk chair and made comfortable. Stimuli were displayed using Tobii Studio on a rear projection screen that was positioned approximately 152 cm in front of the participant. Eye movements were recorded by means of the Tobii X120 stand-alone eye tracker, with a sampling rate of 60 Hz, accuracy of 0.5 degrees of visual angle, spatial resolution of 0.2 degrees, and drift of 0.3 degrees. The device was positioned in front of the participant and below where the stimuli were projected on the screen. Participants were also videotaped during the entire procedure to ensure that they engaged in the task and remained still in the chair.

2.1.3 Stimulus Materials

Six sets of faces (three sets of male faces and three sets of female faces) were created using the following method. For each set of faces, stimuli consisted of 20 exemplars (16 familiarization exemplars and four test exemplars) created by manipulating specific features and spatial distances between features of a photograph of a natural face with average features. The features and spatial distances that were manipulated included nose/mouth distance, nose width, forehead height, and lip thickness. The non-manipulated original face was designated as the "prototype" stimulus (see Figure 1).

Narrow Mode Prototype Wide Mode

Figure 1. Narrow Mode, Prototype, and Wide Mode Stimulus Examples for Experiment 1

Exemplars were generated by manipulating each of the four facial aspects or distances to either be larger or wider than the original (values 3 and 4) or smaller or narrower than the original (values 1 and 2) using the Face Fun facial morphing program. For example, faces were generated that had wider noses than the original (values 3 and 4) and others had narrower noses than the original (values 1 and 2). No exemplar had the same nose width as the original and nose width was manipulated by equal amounts from one value to the next. This was true of all four facial aspects that were manipulated (see Table 2). The nose/mouth distance subtended a visual angle between 1.13 degrees for the narrowest manipulation to 1.70 degrees for the widest manipulation. Nose width subtended a visual angle between 2.75 degrees and 3.20 degrees. Forehead height subtended a visual angle between 4.90 degrees and 6.03 degrees. Lip thickness subtended a visual angle between .94 degrees and 1.51 degrees.

For each set of faces, the familiarization stimuli consisted of 16 stimuli and within these stimuli, each value for each facial aspect or distance was seen four times. For example, for nose width, four faces had a nose width value of 1, four had a value of 2, four had a value of 3, and four had a value of 4. Across all six sets of faces, 96 familiarization stimuli were created. The familiarization face stimuli subtended a visual angle of 12 x 19 degrees.

Four faces that were comprised of all of the same values of each facial aspect (e.g., all values of 1, all values of 2, etc.) were also created for each set of faces. Thus, these faces were comprised of values that were seen an equal number of times during the familiarization trials. The faces comprised of all features with a value of 1 or 4 were designated as the "wide modes", because the difference between the mode and the prototype was the largest (widest) amount possible. The faces comprised of all features with a value of 2 or 3 were designated as the "narrow modes", because the difference between the mode and the prototype was the smallest (narrowest) amount possible. Across all six sets of faces, 16 mode stimuli were created. Table 2 shows example values of the modified facial aspects for the stimuli in each set.

For each set of faces, eight stimulus pairs (test stimuli) were created which consisted of the prototype face (original non-manipulated face) next to one of the narrow modes or the prototype face next to one of the wide modes. For half of the stimulus pairs, the prototype was on the right side of the pair, and for the other half of the stimulus pairs, the prototype was on the left side of the pair. Across all six sets of faces, 48 test stimuli were created. The test stimuli subtended a visual angle of 28 x 19 degrees.

Table 2. Example Values of Modified Facial Aspects for Experiment 1 Stimuli

Stimulus	Nose/Mouth Distance	Nose Width	Forehead Height	Lip Thickness
1	1	1	2	4
2	1	2	3	3
3	1	3	4	1
4	1	4	1	2
5	2	1	3	2
6	2	2	4	1
7	2	3	1	4
8	2	4	2	3
9	3	1	4	2
10	3	2	1	3
11	3	3	2	4
12	3	4	3	1
13	4	1	3	4
14	4	2	4	3
15	4	3	1	2
16	4	4	2	1
Wide Mode	1	1	1	1
Wide Mode	4	4	4	4
Narrow Mode	2	2	2	2
Narrow Mode	3	3	3	3

Familiarization and test stimuli were programmed into four different presentation orders using Tobii Studio. For each presentation order, the six sets of faces were presented in a different predetermined order in blocks. In each block, the familiarization stimuli for one set of faces were presented in randomized order followed by two test trials, first one of the wide modes vs. the prototype (Wide condition), and then one of the narrow modes vs. the prototype (Narrow condition). This was repeated for a total of six blocks. Each test pair was presented an equal number of times across the four different presentation orders, and it was ensured that the prototype was presented on the left and on the right an equal number of times within each presentation order.

2.1.4 Procedure

For each participant, one of the four different presentation orders was randomly selected. Each participant was familiarized with the eye-tracking equipment and seated in a chair approximately 152 cm from the rear projection screen. During calibration, the participant was required to look at the calibration points on the screen in front of him. The calibration procedure was repeated until it was successful. Once the calibration was successfully completed, the participant was provided the following instructions:

“This study involves faces. I am going to show you some faces on the screen one at a time. All you have to do is look at the faces the whole time they are on the screen.”

The participant was then shown the first block of familiarization trials consisting of 16 manipulated face exemplars in a randomized order. All familiarization faces remained on the screen for two seconds with an interstimulus interval of one second. At the end of the familiarization period, the participant was given a response pad with two buttons. Above the left button was an arrow pointing to the left side of the screen and above the right button was an arrow pointing to the right side of the screen. The participant was then given the following instructions:

"Now you are going to see two faces on the screen at the same time. I want you to decide which face looks more familiar to you. In other words, which face looks like you have seen it before? See how each button has an arrow pointing to one side of the screen? When you have decided which face is more familiar, I want you to push the button that goes with that face. It is important for you to push the button as quickly as possible. Ready?"

Once the participant was ready, the first test trial was presented. This trial consisted of the prototype face vs. one of the wide modes (Wide condition). Once the participant responded as to which face was more familiar, a white screen was presented followed by the second test trial. This trial consisted of the prototype face vs. one of the narrow modes (Narrow condition). Each test trial remained on the screen until the participant responded by pressing a button.

Following the first block of trials and before each subsequent block of trials, an instruction slide was presented and the following instructions were given:

"Now you are going to see more faces of a new person. All you have to do is look at the faces the whole time they are on the screen."

Following the second set of familiarization trials and before each new set of test trials, the following instructions were given:

"Now you are going to see two faces again. I want you to decide which face looks more familiar to you, like you have seen it before. When you have decided, push the button that goes with that face. Remember, it is important for you to push the button as quickly as possible. Ready?"

This procedure was repeated until all six blocks of trials were completed. During the entire procedure, the participant's eye movements were recorded in order to determine which part(s) of the face the participant looked at when viewing the familiarization faces. The participant's responses were also recorded by Tobii Studio.

Following the completion of the experiment, each participant was administered the Kaufman Short Neuropsychological Assessment Procedure (K-SNAP) Gestalt Closure subtest in order to measure low-level perception. The K-SNAP Gestalt Closure consists of 25 partially completed inkblot pictures. Participants were shown each inkblot one at a time and asked, "What is this?" Their responses were recorded, and administration was discontinued when the participant produced five consecutive incorrect answers. All raw scores were converted to T-scores for use in analyses. This measure was included in order to provide information about how participants processed perceptual information. Specifically, it was aimed at determining whether participants showed strong central coherence and were able to use global perceptual processing to "fill-in" the inkblots into a coherent picture or whether they evidenced weak central coherence or enhanced local processing and had difficulty with this task.

2.1.5 Eye-tracking Data Preparation (AOIs)

All familiarization stimuli were partitioned into areas of interest (AOIs) corresponding to the following areas: eyes, nose, mouth, forehead, face, and whole stimulus. The Eyes AOI was drawn as a box that extended vertically from the top of the eyebrows to the bottom of the orbital and horizontally from the left hairline to the right hairline. The Nose AOI was drawn as a box that extended vertically from the Eyes AOI to halfway between the nose and the mouth and horizontally from slightly to the left of the outer edge left nostril to slightly to the right of the outer edge of the right nostril. The distance between the top lip and the Nose AOI was measured, and this distance was used to determine the bottommost point of the Mouth AOI (e.g., the same distance below the bottommost point of the bottom lip). Therefore, the Mouth AOI was drawn as a box that extended vertically from the Nose AOI to the calculated point below the bottom lip and horizontally from the left edge of the face to the right edge of the face. The Forehead AOI was drawn to include the entire forehead area. The Forehead AOI extended vertically from the upper hairline to the Eyes AOI and horizontally from the left hairline to the right hairline. The Face AOI was drawn to include the whole face while excluding the hair and ears. The Stimulus AOI (labeled All in Figure 2) was drawn as a box that included the entire stimulus (background and face). Figure 2 shows an example of all AOIs.

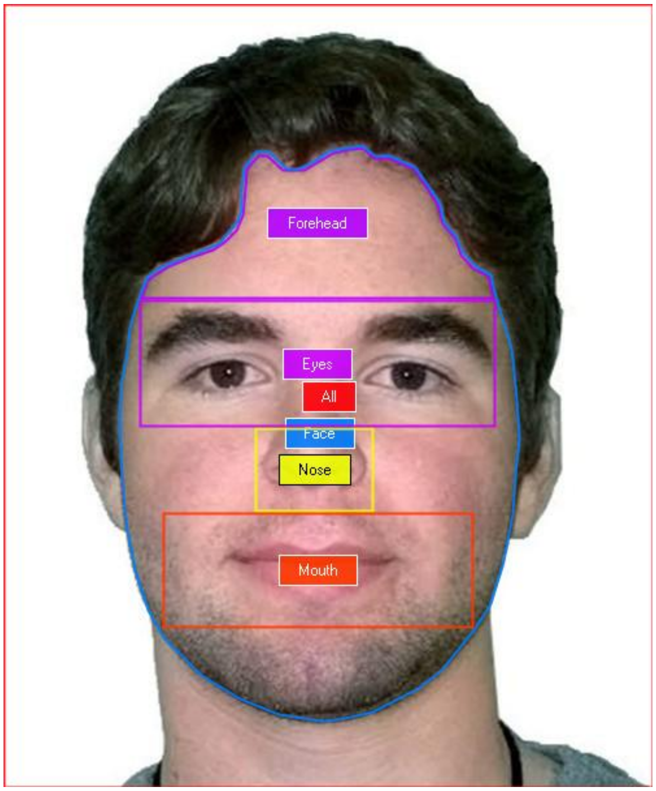


Figure 2. Example AOIs for Experiment 1

2.2 RESULTS

2.2.1 Percent Prototype Selection Data

The first aim of Experiment 1 was to investigate whether individuals with autism, in contrast to typically developing individuals, have difficulty abstracting prototypes of facial information. Individuals who abstract a prototype are expected to consider the prototype to be more familiar than the modal faces. Individuals who experience difficulty with prototype formation will not consider the prototype faces to be more familiar than the modal faces. In order to address this aim, the percentage of prototype faces selected as familiar was the main dependent measure of interest. This percentage provided a measure of how often the prototype faces were considered to be more familiar than the modal faces. If a facial prototype was formed during the familiarization phase, the prototype faces would be considered to be more familiar than the modal faces.

A Mean Prototype Score (MPS) for each Condition (Narrow and Wide) was calculated across the six test trials by counting the number of times that the prototype was chosen as familiar, dividing that number by six, and multiplying the result by 100. A 2-way ANOVA was conducted on the MPS data. The between subjects variable was Group (Autism vs. Control) and the within subject variable was Condition (Narrow vs. Wide). Results indicated a trend toward a significant main effect of Condition, F (1, 38) = 3.76, $p < .06$, with the prototype faces being selected as familiar more often in the Wide condition (M = 61.67%) than the Narrow condition (M = 50.83%) across both groups. Results indicated a significant main effect of Group, F (1, 38) = 6.95, $p < .05$ with the Control group (M = 62.50%) selecting the prototype faces as familiar more often than the Autism group (M = 50.00%).

The Group X Condition interaction approached significance, *F* (1, 38) = 2.69, *p* = .11. The MPS data by Condition is presented in Figure 3. As can be seen, the Autism (*M* = 50.83%) and Control (*M* = 72.5%) groups significantly differed in their Mean Prototype Scores in the Wide condition with the Control group selecting the prototype faces as familiar more often than the Autism group (*t* = -2.96, *p* < .01). While the Autism group did not select the prototype faces as familiar more often than chance (50%) (*t* = .17, *p* = .87), the Control group showed clear familiarity for the prototype faces in the Wide condition (*t* = 4.13, *p* < .01). The results for the Narrow condition are quite different. In the Narrow condition, the Autism (*M* = 49.17%) and Control (*M* = 52.50%) groups did not significantly differ in their Mean Prototype Scores, (*t* = -.46, *p* =.65). In fact, neither of these percentages differed from chance (50%) (*t* = -.15, *p* = .88 for the Autism group and *t* = .51, *p* = .61 for the Control group). Thus, neither the Autism nor the Control group identified the prototype faces as more familiar then the modal faces in the Narrow condition.

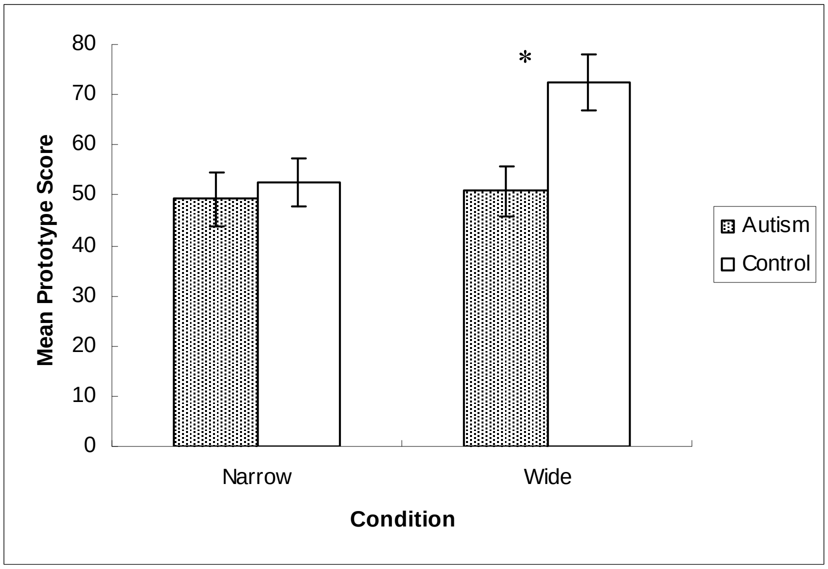


Figure 3. Mean Prototype Scores by Condition (* *p* < .05)

While these analyses provide important information regarding between group differences in the Mean Prototype Scores, they do not address potential differences in the range or distribution of scores between the two groups. For instance, were there more participants in the Control group who showed clear evidence of face prototype formation? Were there more participants in the Autism group who showed clear evidence of a lack of face prototype formation?

Figure 4 presents the distribution of performance in the Wide Condition across groups as a frequency plot of the number of participants in each group who chose one, two, three, four, five, or six of the prototype stimuli as familiar. The Wide condition is presented since neither group identified the prototype faces are more familiar in the Narrow condition. It can be seen that nine out of twenty participants in the Control group showed clear evidence of face prototype formation by choosing the prototype faces as familiar in five or six out of six trials. However, only three participants in the Autism group showed clear evidence of prototype formation. In contrast, five participants in the Control group and twelve participants in the Autism group showed clear evidence of a lack of prototype formation by choosing the prototype as familiar in three or fewer trials. Five participants in the Autism group and six participants in the Control group chose the prototype faces as familiar in four out of six trials. Since choosing the prototype face as familiar in three out of six trials can be considered to be random or chance level performance, it is difficult to know whether choosing the prototype in four out of six trials is evidence of prototype formation or not. A chi-square analysis comparing the distribution of clear prototype formers (n = 3 in the Autism group, n = 9 in the Control group) and clear non-prototype formers (n = 12 in the Autism group, n = 5 in the Control group) revealed a significant association between diagnosis and prototype formation, $\chi^2(1) = 5.86$, $p < .05$. Based on the odds ratio, individuals in the Control group were 7.20 times more likely to show clear evidence of prototype formation than were individuals in the Autism group.

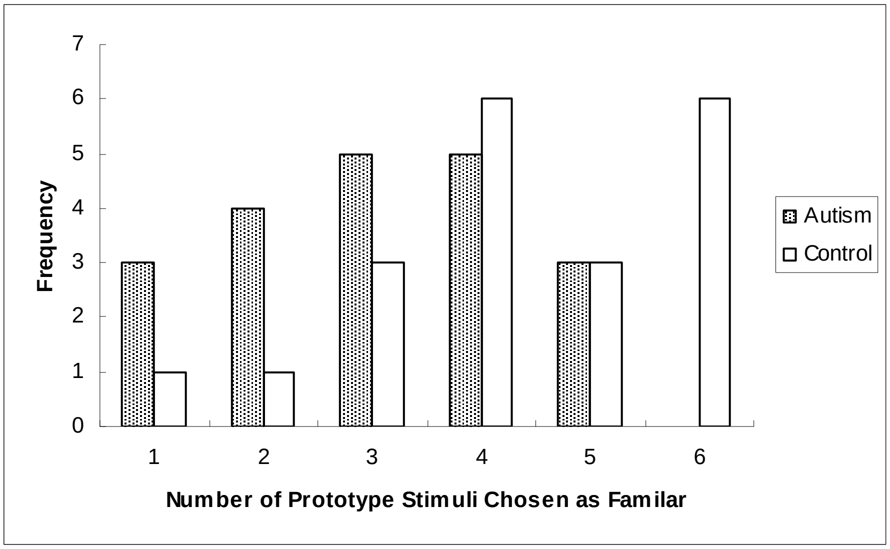


Figure 4. Distribution of Performance in the Wide Condition across Groups

2.2.2 Relationship between Prototype Formation and Other Abilities

The second aim of Experiment 1 was to determine whether facial prototype formation ability is related to measures of intelligence, low-level perceptual processing, or the social, communication, or behavioral symptoms of autism. Correlations between the Mean Prototype Scores and measures of intelligence (VIQ, PIQ, and FSIQ), low-level perceptual processing (K-SNAP Gestalt Closure T-Score), and the social, communication, and behavioral symptoms of autism (ADOS Social Interaction Total Score, ADOS Communication Total Score, ADOS Social Interaction and Communication Total Score, and ADOS Stereotyped Behavior and Restricted Interests Total Score) were calculated. The correlations were calculated separately for the Autism group and the Control group since different variables may be related to performance in each group. Correlations were only calculated for the Wide condition since neither group identified the prototype faces as more familiar in the Narrow condition.

The correlations between performance on the face prototype task and the other measures are presented in Table 3. It can be seen that the only significant correlation in the Autism group was between performance on the face prototype task and the Stereotyped Behavior and Restricted Interests Total Score on the ADOS, $r = -.70$, $p < .01$. The Stereotyped Behavior and Restricted Interests Total Score on the ADOS is a summary score made up of subscores including unusual sensory interest in play materials or people, hand and finger and other complex mannerisms, excessive interest in unusual or highly specific topics or objects, and compulsions or rituals. This correlation suggests that poorer performance on the face prototype task was related to a higher number of these types of behaviors. For the Control group, the only significant correlation was between performance on the face prototype task and FSIQ, $r = .45$, $p < .05$. A closer examination of a scatterplot of the data suggested that the correlation was being substantially affected by one participant with a lower FSIQ and lower performance on the face prototype task. When this subject was excluded, the correlation was no longer significant, $r = .29$, $p = .22$. Therefore, it appears that individuals with autism with a higher number of stereotyped behaviors and restricted and repetitive interests performed more poorly on the face prototype task. Formation of a face prototype was not related to intelligence or performance on a low-level perceptual task in either group or to social or communication difficulties in the Autism group.

Table 3: Correlations Between Face Prototype Task Performance and Measures of Intelligence, Symptoms of Autism, and Low-level Perceptual Processing

Variable	Autism ($n = 20$)	Control ($n = 20$)	Control ($n = 19$)
VIQ	0.03	0.39	0.13
PIQ	0.13	0.41	0.34
FSIQ	0.11	0.45*	0.29
ADOS Social Interaction Total	0.11		
ADOS Communication Total	0.06		
ADOS Social Interaction and Communication Total	0.10		
ADOS Stereotyped Behavior and Restricted Interests Total	-0.70**		
K-SNAP Gestalt Closure T-Score	0.38	0.09	0.13

** $p < .01$
* $p < .05$

2.2.3 Eye-tracking Results

The third aim of Experiment 1 was to use eye-tracking technology to investigate what areas of the stimulus and/or face typically developing individuals and individuals with autism attend to or look at when forming a prototype of faces. Of the 20 individuals with autism and 20 control individuals, 14 individuals in each group were included in the eye-tracking analyses. Six participants in each group were excluded due to poor eye-tracking data (e.g., poor calibration or lack of accurate eye-tracking). As with the full participant set, no significant differences were found between the two groups on age, FSIQ, VIQ, or PIQ.

Of interest was whether the Autism and Control groups differed in the distribution of time or proportion of time that they spent looking (% LT) at the face or relevant features during the familiarization trials. Differences in the distribution of time spent looking at the face or relevant features could provide important information about *why* the Autism group did not choose the prototype faces as more familiar. For example, if the Autism group spent less time looking at the faces and more time looking at the background, they would be less likely to form a prototype during the familiarization phase. Similarly, if the Autism group spent less time looking at relevant facial features such as the eyes, nose, mouth, and forehead and more time looking at irrelevant features such as the cheeks or hairline, they would be less likely to form a prototype. Finally, if the Autism Group focused solely on one facial feature, this would affect their ability to form a prototype of the entire face.

In order to answer these questions, the dependent measure of interest was the % LT for each AOI (% Eyes, % Nose, % Mouth, % Forehead, and % Face). To calculate the % LT, the observation length or the total amount of time spent looking at each AOI was summed across all of the familiarization trials. The % LT for each AOI was then calculated by dividing the total amount of time the participant spent looking at each AOI (e.g., Eyes) by the total amount of time the participant spent looking at all of the relevant features (i.e., Eyes + Nose + Mouth + Forehead) and multiplying the result by 100.

Before the % LT data was analyzed, it was important to determine whether the Autism and Control groups differed in the amount of time that they spent looking at the Face AOI vs. the Stimulus AOI (% Face). In other words, did the Autism and the Control group differ in the proportion of time that they spent looking at the face vs. irrelevant aspects of the stimulus (the background). The % Face was calculated by dividing the total amount of time that participants spent looking at the Face AOI (across all familiarization trials) by the total amount of time that they spent looking at the Stimulus AOI (across all familiarization trials) and multiplying the result by 100. An independent samples t-test determined that the Autism group ($M = 93.03\%$) and Control group ($M = 91.21\%$) did not differ in the percentage of time that they spent looking at the faces, $t = 1.14$, $p = .26$. Therefore, the difference between the Autism group and Control group in prototype formation ability was not due to a differential amount of time spent looking at the faces.

As stated above, another possibility to consider is whether the Autism and Control groups differed in the amount of time that they spent looking at relevant aspects of the face vs. irrelevant aspects of the face (% Relevant). The % Relevant score was calculated by dividing the total amount of time that the participants spent looking at the Eyes, Mouth, Nose, and Forehead AOIs (across all familiarization trials) by the total amount of time that they spent looking at the Face AOI (across all familiarization trials) and multiplying the result by 100. An independent samples t-test resulted in a marginally significant difference between the Autism group ($M = 95.09\%$) and Control group ($M = 98.69\%$) indicating that the Control group spent slightly more time looking at the relevant aspects of the faces than the Autism group, $t = -1.75$, $p = .09$. Therefore, it is possible that the difference between the Autism group and Control group in prototype formation ability may have been due to the Autism group spending less time looking at the relevant aspects of the faces. However, since the Autism group looked at the relevant facial features 95% of the time, it is unlikely that less attention to relevant features can account for the lack of a familiarity preference for the prototype faces in the Autism group.

Finally, the % LT data was analyzed in order to examine differences in the distribution of time spent looking at the relevant features between the Autism group and the Control group. The % LT data is presented in Figure 5. A 2-way ANOVA was conducted on the % LT data. The between subjects variable was Group (Autism vs. Control) and the within subject variable was Feature (Eyes vs. Nose vs. Mouth vs. Forehead). Results indicated a significant main effect of Feature, $F\ (3, 78) = 33.23$, $p < .01$. Post-hoc comparisons (Holm-Bonferroni) resulted in significant differences between all of the features indicating that both groups spent the largest proportion of time looking at the eyes (*M* = 48.33%) followed by the nose (*M* = 32.81%), mouth (*M* = 16.99%), and forehead (*M* = 1.87%) ($p < .01$ for all comparisons except Eyes vs. Nose, $p < .05$). In other words, both groups had the same general pattern of attention to the facial features. There was no significant main effect for Group, (F (1, 26) = 1.74, $p = .20$) nor a significant interaction between Group and Condition (F (3, 78) = 1.90, $p = .14$). In general, the Control group (*M* = 25.00%) did not differ from the Autism group (*M* = 25.00%) in the mean percent of time that they spent looking at the features.

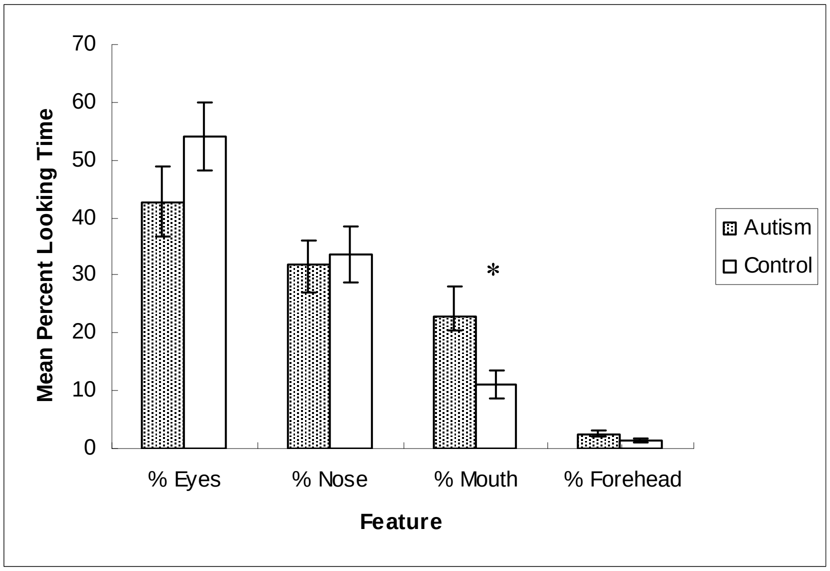


Figure 5. Mean Percent Looking Time by Feature (* *p* < .05)

Also of interest was whether there were any between group differences in the percentage of time spent looking at each feature. Independent samples t-tests were performed on the % LT data for each feature. As can be seen in Figure 5, the groups did not differ in the percentage of time spent looking at noses or foreheads ($t = -.26$, $p = .80$ for % Nose and $t = 1.34$, $p = .19$ for % Forehead). The Autism group (*M* = 42.65%) spent a smaller percentage of time looking at eyes than the Control group (*M* = 54.01%), but this difference did not reach significance, *t* = -1.31, *p* = .20. This is likely due to the high variability in the % Eyes scores in both groups. In contrast, the Autism group (*M* = 22.95%) spent a larger percentage of time looking at mouths than the Control group (*M* = 11.02%). This difference reached statistical significance, *t* = 2.16, *p* < .05. Therefore, even though the Autism group spent more time looking at the eyes than any other feature of the face, they spent less time looking at the eyes and more time looking at the mouth than the Control Group.

2.2.4 Subset Analyses

The final aim of Experiment 1 was to examine individual differences in the ability to abstract prototypes in individuals with autism. More specifically, it was concerned with whether there was a subset of individuals with autism who were able to successfully form a facial prototype. Of particular interest is whether individuals with autism who were able to successfully form a prototype differed from those who performed poorly on the facial prototype task on measures of intelligence, low-level perceptual processing, symptoms of autism, or eye-tracking measures. To this end, the 20 participants with autism were grouped into two subgroups, prototype formers and non-prototype formers. Prototype formers were defined as individuals who chose the prototype as familiar in four or more of the six test trials in the Wide condition. Non-prototype formers were defined as individuals who chose the prototype as familiar in three or fewer trials in the Wide condition. The Wide condition was chosen, because neither group showed evidence of prototype formation in the Narrow condition.

Table 4: Means and Standard Deviations for Measures of Intelligence, Symptoms of Autism, Low-level Perceptual Processing, and Eye-tracking for Prototype Formers and Non-prototype Formers for the Face Prototype Experiment

Variable	Prototype Formers ($n = 8$) M (SD)	Non-prototype Formers ($n = 12$) M (SD)
VIQ	109. 38 (10.10)	106.08 (11.43)
PIQ	105.87 (13.27)	109.92 (13.55)
FSIQ	108.00 (6.91)	109.08 (10.70)
ADOS Social Interaction Total	9.50 (1.60)	8.92 (1.24)
ADOS Communication Total	5.25 (1.58)	5.17 (.83)
ADOS Social Interaction and Communication Total	14.75 (3.11)	14.08 (1.38)
ADOS Stereotyped Behavior and Restricted Interests Total **	1.13 (.83)	3.00 (1.60)
K-SNAP Gestalt Closure T-Score	57.88 (9.00)	54.92 (10.16)
Variable	Prototype Formers ($n = 7$) M (SD)	Non-prototype Formers ($n = 7$) M (SD)
% Face	92.25 (2.66)	93.81 (3.97)
% Relevant features	95.42 (7.28)	94.76 (2.55)
% Eyes	41.84 (19.75)	43.45 (28.97)
% Nose	34.38 (12.66)	29.64 (17.16)
% Mouth	21.75 (20.51)	24.16 (18.24)
% Forehead	2.02 (2.39)	2.76 (2.39)

** $p < .01$

The means and standard deviations for the measures of intelligence, low-level perceptual processing, symptoms of autism, and eye-tracking for the prototype formers (n = 8 for most measures, n = 7 for eye-tracking measures) and non-prototype formers (n = 12 for most measures, n = 7 for eye-tracking measures) are presented in Table 4. Independent samples t-tests showed that the only significant difference between the two subgroups was that the prototype formers (M = 1.13) had a significantly lower Stereotyped Behavior and Restricted Interests Total Score on the ADOS than the non-prototype formers (M = 3.00), t = 3.04, $p < .01$. As with the correlations, this suggests that individuals with autism who were able to form a prototype of facial information had a lower number of stereotyped and repetitive behaviors. No other between group comparisons were significant.

A limitation of using the criteria of four out of six trials is that, since choosing the prototype face as familiar in three out of six trials can be considered to be random or chance level performance, it is difficult to know whether choosing the prototype in four out of six trials is evidence of prototype formation or not. Therefore, a second set of subgroups were formed using a more stringent definition of prototype former. For this set, prototype formers were defined as individuals who chose the prototype as familiar in five or more of the six test trials in the Wide condition. Non-prototype formers were defined the same way as in the first set of analyses. Individuals who chose the prototype as familiar in four trials were excluded from these subgroups.

The means and standard deviations for the measures of intelligence, low-level perceptual processing, symptoms of autism, and eye-tracking for the prototype formers (n = 3) and non-prototype formers (n = 12 for most measures, n = 7 for eye-tracking measures) using a more stringent classification criteria are presented in Table 5. Due to the small sample size for the prototype formers, formal statistical tests could not be performed on this data. However, similar to the analyses using the less stringent criteria, prototype formers (M = 1.00) had a lower Stereotyped Behavior and Restricted Interests Total Score on the ADOS than the non-prototype formers (M = 3.00). Again, this suggests that individuals with autism who showed clear evidence of the ability to form a prototype had a lower number of stereotyped and repetitive behaviors. An additional difference that emerged when more stringent criteria were used was that prototype formers (M = 66.67) had higher K-SNAP Gestalt Closure T-scores than non-prototype formers (*M* = 54.92). This suggests that individuals with autism who showed clear evidence of prototype formation had a greater ability to engage in global processing or had less of a local processing bias than those who were unable to form a prototype of facial information. No other between group comparisons were significant.

Table 5: Means and Standard Deviations for Measures of Intelligence, Symptoms of Autism, Low-level Perceptual Processing, and Eye-tracking for Prototype Formers and Non-prototype Formers for the Face Prototype Experiment using Stringent Criteria

Variable	Prototype Formers (n = 3) *M* (*SD*)	Non-prototype Formers (n = 12) *M* (*SD*)
VIQ	107.33 (11.50)	106.08 (11.43)
PIQ	116.00 (7.81)	109.92 (13.55)
FSIQ	112.33 (4.16)	109.08 (10.70)
ADOS Social Interaction Total	8.67 (.58)	8.92 (1.24)
ADOS Communication Total	4.67 (.58)	5.17 (.83)
ADOS Social Interaction and Communication Total	13.33 (1.15)	14.08 (1.38)
ADOS Stereotyped Behavior and Restricted Interests Total	1.00 (1.00)	3.00 (1.60)
K-SNAP Gestalt Closure T-Score	66.67 (3.51)	54.92 (10.16)
	Prototype Formers (n = 3) *M* (*SD*)	Non-prototype Formers (n = 7) *M* (*SD*)
% Face	91.53 (1.89)	93.81 (3.97)
% Relevant features	93.91 (9.69)	94.76 (2.55)
% Eyes	32.65 (20.13)	43.45 (28.97)
% Nose	41.42 (14.74)	29.64 (17.16)
% Mouth	24.08 (11.11)	24.16 (18.24)
% Forehead	1.85 (2.16)	2.76 (2.39)

2.3 DISCUSSION

The first aim of Experiment 1 was to investigate whether individuals with autism, in contrast to typically developing individuals, experienced difficulty abstracting prototypes of facial information. Results indicated that the Control group chose the prototype faces as familiar 72.5% of the time in the Wide condition. As was hypothesized, the Control group was able to distinguish the prototype faces from the modal faces and found the prototype faces to be more familiar than faces comprised of features that were previously seen during the familiarization phase. In contrast, the individuals with autism did not choose the prototype faces as familiar at a level greater than chance in the Wide or Narrow conditions. This result supports the second hypothesis suggesting that the individuals with autism had a deficit in face prototype formation. The third hypothesis was also supported in that the Control group chose the prototype faces as familiar more often than the Autism group. This finding was true for the Wide condition but not the Narrow condition. In fact, in the Wide condition, nine out of twenty participants in the Control group showed clear evidence of face prototype formation by choosing the prototype faces as familiar five or six out of six trials while only three participants in the Autism group showed clear evidence of prototype formation. It is important to note that neither group chose the prototype faces as familiar at greater than chance levels in the Narrow condition. It is possible that the prototype and modal faces were indistinguishable from each other in the Narrow condition, resulting in chance behavior in both groups.

While no specific hypotheses were made, the second aim was to determine whether facial prototype formation ability was related to measures of intelligence, low-level perceptual processing, or the social, communication, or behavioral symptoms of autism. There were no significant correlations in the Control group once an outlier participant was removed from the data indicating that performance on the face prototype task was not related to intelligence or low-level perceptual processing. The only significant correlation in the Autism group was between performance on the face prototype task and the Stereotyped Behavior and Restricted Interests Total Score on the ADOS. The Stereotyped Behavior and Restricted Interests Total Score on the ADOS is a summary score made up of subscores including unusual sensory interest in play materials or people, hand and finger and other complex mannerisms, excessive interest in unusual or highly specific topics or objects, and compulsions or rituals. This correlation suggests that poorer performance on the face prototype task was related to a higher number of these types of behaviors. It is possible that individuals with autism who tend to focus intensely on details, parts or irrelevant aspects of objects, or topics of interest are also more likely to focus on specific aspects of the face rather than the whole face which would negatively affect prototype formation. It is also possible that individuals with autism who do not focus intensely on details, parts or irrelevant aspects of objects, or topics of interest are also less likely to focus on specific aspects of the face rather than the whole face which would positively affect prototype formation. These possibilities will be discussed in more detail in the General Discussion.

The third aim was to use eye-tracking technology to investigate what areas of the stimulus and/or face typically developing individuals and individuals with autism attended to or looked at when forming a prototype of faces. Eye-tracking data was collected during the familiarization trials in order to address *why* the Autism group did not choose the prototype faces as more familiar. Differences in the distribution of time spent looking at the face or relevant features may provide potential explanations for these results. Examination of eye fixation patterns indicated that, as hypothesized, the Autism and Control groups did not differ in the amount of time spent looking at the faces. Therefore, the difference between the Autism group and Control group in prototype formation ability was not due to a differential amount of time spent looking at the faces during the familiarization trials. Also as hypothesized, individuals with autism were found to spend less time looking at relevant aspects of the faces during the familiarization trials than the Control group. However, this difference was small, and on average, the Autism group spent 95% of the time that they were looking at the faces looking at relevant facial features. Therefore, it is also unlikely that the difference between the Autism group and the Control group in prototype formation ability was due to limited attention to relevant facial features.

Examination of between group differences in the percentage of time spent looking at each feature determined that even though the Autism group spent more time looking at the eyes than any other facial feature, they spent a smaller percentage of time looking at eyes and a larger percentage of the time looking at mouths than the Control group. However, the general pattern of attention to the faces for both groups was similar suggesting that differential attention to features does not explain the difficulty that the individuals with autism had in the abstraction of facial prototypes. This will be discussed in more detail in the General Discussion section.

The final aim was to examine individual differences in the ability to abstract prototypes in the Autism group. A closer examination of individual participant's data in the Autism group indicated that there was a subset of individuals with autism who were able to form a prototype of facial information in the Wide condition. A generous definition of prototype former (chose the prototype face as familiar in four or more out of six trials) identified eight individuals with autism who performed well on the face prototype task while a stringent definition of prototype former (chose the prototype face as familiar in five or six out of six trials) identified three individuals with autism with intact facial prototype formation abilities. An important question is whether individuals with autism who were able to form a prototype of facial information differed from those who were unable to do so successfully. Results indicated that the individuals with autism who performed best on the facial prototype formation task had fewer restricted and repetitive behaviors and interests and had higher scores on the K-SNAP Gestalt Closure task. This suggests that there is a small subset of individuals with autism who may be less likely to focus intensely on topics and details and may have stronger global processing skills or less "weak central coherence." These possibilities will be addressed more closely in the General Discussion.

From this experiment, it is unknown whether these results were specific to facial information or reflective of a general deficit in prototype formation abilities in individuals with autism. It can be argued that since faces are social, the deficit in prototype formation of facial information is a result of a general deficit in social information processing. In order to determine whether there is a general deficit in prototype formation abilities that is present in individuals with autism, a second experiment involving non-social stimuli (dot patterns) was performed. If individuals with autism have a general prototype formation deficit, they will also experience difficulty forming a prototype of dot patterns.

3.0 EXPERIMENT 2: DOT PROTOTYPE

3.1 METHOD

3.1.1 Participants

All recruiting, inclusion, exclusion and matching criteria were identical to Experiment 1. While the same number of participants were included in Experiment 2 as in Experiment 1 (20 high-functioning adult males with autism and 20 healthy control adult males), the actual participants differed slightly due to equipment difficulties and/or experimenter error. However, 17 participants in each group were included in both Experiment 1 and 2. Table 6 summarizes the participants' demographic characteristics for Experiment 2. Again, no significant differences were found between the two groups on age, FSIQ, VIQ, or PIQ.

Table 6. Participants' Diagnostic and Demographic Characteristics for Experiment 2

	Autism Group (*n* = 20)		Control Group (*n* = 20)	
	M (*SD*)	(Range)	*M* (*SD*)	(Range)
CA	23.40 (6.64)	(17-37)	26.45 (6.21)	(18 – 37)
VIQ	108.55 (9.83)	(89 – 127)	112.85 (4.94)	(100 – 122)
PIQ	110.70 (12.41)	(83 – 131)	112.40 (8.13)	(93 – 125)
FSIQ	110.55 (7.67)	(98 – 128)	114.30 (6.07)	(97 – 121)

Note. CA = Chronological Age in years; VIQ = Verbal IQ; PIQ = Performance IQ; FSIQ = Full Scale IQ

3.1.2 Apparatus

The testing apparatus was identical to Experiment 1.

3.1.3 Stimulus Materials

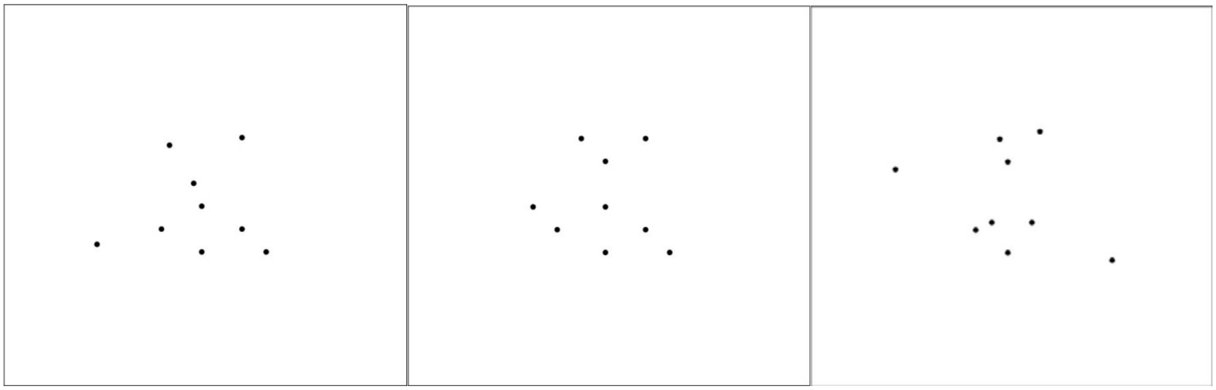
Stimuli were constructed following procedures used by Kéri, Kálmán, et al. (2001). All stimuli were created in Excel using a 50 x 50 cell matrix. The dot prototype was constructed by placing nine filled dots into the central 30 x 30 cell area in a pattern very similar to that used as the prototype in Kéri, Kálmán, et al. (2001). Each within category stimulus was constructed by systematically distorting the placement of each dot according to a subset of the statistical rules and procedures that were used to create distortions of prototype stimuli in a set of studies by Posner, Goldsmith, and Welton (1967). These statistical rules and procedures have been used by many researchers studying dot prototype formation in typically developing and clinical populations (e.g., Kéri, Kálmán et al., 2001; Knowlton & Squire, 1993; Zaki & Nosofsky, 2007). Within category stimuli consisted of 20 low distortions of the prototype and 60 high distortions of the prototype. The low distortions were formed using the statistical rules that correspond to Posner et al. (1967) distortion level three and the high distortions were formed using the statistical rules that correspond to distortion level six. Table 7 shows the statistical rules for low and high distortions.

Table 7. Probabilities of Moving to Each Area for Low and High Levels of Distortion

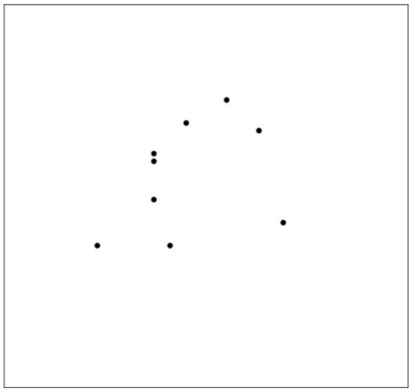
	Area				
Level of Distortion	1	2	3	4	5
Low	.59	.20	.16	.03	.02
High	.20	.30	.40	.05	.05

The stimuli were created using the following procedure. A template of 400 cells was constructed with the center cell labeled zero, the surrounding eight cells labeled 1-8, the next ring of cells numbered 9-24, and the remaining cells numbered 25-399 in a clockwise spiral fashion. Five areas, as seen in Table 7, were assigned consisting of Area 1 (the central cell, cell zero), Area 2 (cells 1-8), Area 3 (cells 9-24), Area 4 (cells 25-99), and Area 5 (cells 100-399). Each stimulus began as the prototype. The template was placed over the first dot and a statistical calculator was used to calculate which cell of the template the dot would move to according to the corresponding probabilities for that stimulus. The dot was then moved to the cell on the 50 x 50 grid that corresponded to the cell on the template that was chosen. This was repeated for all nine dots for that stimulus. Thus, for the low distortion stimuli, each dot had a .59 probability of staying in place (Area 1), .20 of moving to Area 2, .16 to Area 3, .03 to Area 4, and .02 to Area 5. As a result, the low distortion stimuli were very similar to the prototype stimulus in form. The dots in the high distortion stimuli had a zero probability of staying in the same position, and therefore all high distortion stimuli were guaranteed to consist of a pattern of dots that was less similar to the prototype than the low distortions but was still within the same category of dot patterns as the prototype, low distortions, and other high distortions.

In addition to the within category dot stimuli, 40 non-category dot patterns were created by making 40 high distortions of a completely different dot pattern using the same statistical principles as those that were used to make the within category dot patterns. In total, the stimuli consisted of a prototype, 20 low distortions, 60 high distortions, and 40 non-category stimuli (high distortions of a different dot pattern). Figure 6 depicts an example of each of these types of stimuli.



Low Distortion Prototype High Distortion



Non-category

Figure 6. Examples of Experimental Stimuli for Experiment 2

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

3.1.4 Procedure

As with Experiment 1, each participant was familiarized with the eye-tracking equipment and seated in a chair approximately 152 cm from the rear projection screen. During calibration, the participant was required to look at the calibration points on the screen in front of him. The calibration procedure was repeated until it was successful. Once the calibration was successfully completed, the participant was provided the following instructions:

“This study involves dot patterns. You will see dot patterns on the screen in front of you. The dot patterns will be on the screen for a few seconds and then will disappear. Your job is to look at the dot patterns the whole time they are on the screen. Do you have any questions?” The experimenter answered any questions and then proceeded to present the familiarization trials.

The procedure for Experiment 2 was identical to that used by Kéri, Kálmán, et al. (2001). During the familiarization trials, participants were presented with 40 high distortions of the prototype. These stimuli were presented in a random order and were on the screen for five seconds with an interstimulus interval of one second. During the interstimulus interval, a grayscale striped gradient was presented in order to decrease the amount of afterimage that was created by the previously seen dot stimulus.

Following the familiarization phase, there was a five minute break in which the participant was permitted to stand up and move around but otherwise did not engage in any other tasks. After this delay period, the participant was reseated and recalibrated. The participant was given a response pad with two buttons labeled “yes” and “no”. The participant was then given the following instructions:

“Now I am going to show you more dot patterns and your job is to decide if they look familiar to you, like you have seen them before. Some dot patterns will look familiar to you (like you have seen them before) and will look like they belong to the same group of dot patterns that you saw earlier. Others will look like they belong to a group of dot patterns that you have never seen before. I want you to press ‘yes’ if the dot pattern belongs to the group of dot patterns you saw earlier. I want you to press ‘no’ if the dot pattern belongs to a different group of dot patterns that you have never seen before. It is important for you to answer as quickly yet as accurately as possible. If you are not sure of the answer, just make your best guess. Now I am going to have you practice pressing the buttons. Press the ‘yes’ button. Now press the ‘no’ button. Do you have any questions?” The experimenter answered any questions and then proceeded to present the test trials.

During the test trials, participants were presented with four instances of the prototype, 20 low distortions of the prototype, 20 new high distortions of the prototype, and 40 non-category dot patterns in randomized order. Each stimulus was presented until the participant responded by pressing a button on the response pad. Participants responded using a response pad with two buttons labeled “yes” and “no”. The left-right orientation of the labels was counterbalanced across participants. During the entire procedure the participants eye movements were recorded in order to determine which part(s) of the dot patterns the participant looked at when viewing the familiarization patterns. The participant’s responses were also recorded by Tobii Studio.

3.1.5 Eye-tracking Preparation (AOIs)

All familiarization stimuli were partitioned into areas of interest (AOIs) corresponding to each dot, the figure, and the whole stimulus. Each Dot AOI was drawn as circle with a 15 mm diameter. The AOI was placed so that the dot was in the exact center of the circle. If two dots in a stimulus were in positions that would result in the Dot AOIs overlapping, one Dot AOI was drawn that included both dots as part of that AOI. When this occurred, the AOI was placed so that each dot was equally included in the AOI (see Figure 7). The Figure AOI was drawn as a box that extended vertically and horizontally to include all nine dots. The Stimulus AOI was drawn as a box that included the entire stimulus (background and dots). Figure 7 shows an example of all AOIs.

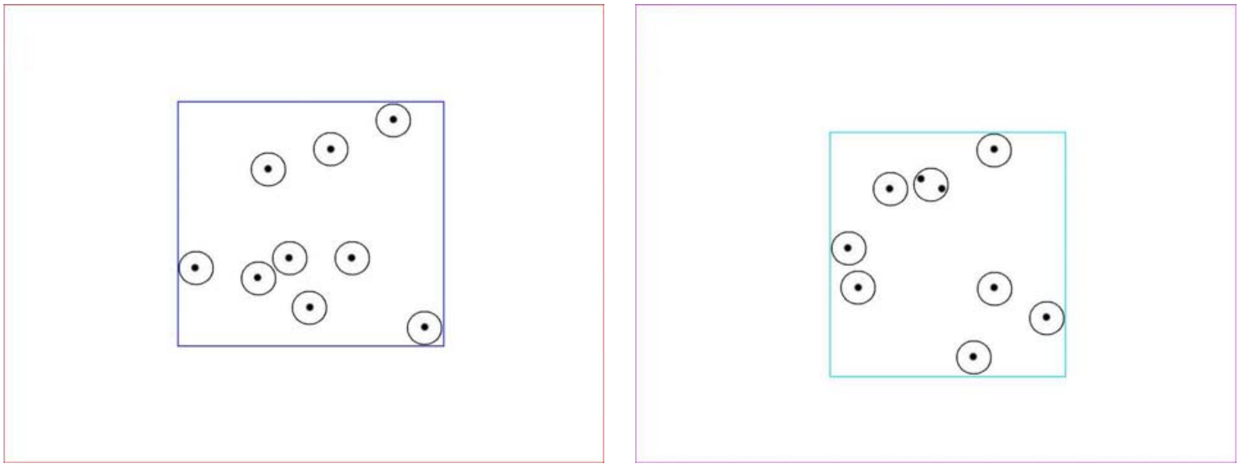


Figure 7. Examples AOIs for Experiment 2

3.2 RESULTS

3.2.1 Percent Endorsed Data

The first aim of Experiment 2 was to investigate whether individuals with autism, in contrast to typically developing individuals, experience difficulty abstracting prototypes of dot pattern information. During the test phase, the participants were asked to identify whether the presented dot patterns were members of the same category of dot patterns that they had seen during the familiarization phase or a different category of dot patterns that they had never seen before. Individuals who successfully abstract a prototype and form a well-defined category of the dot patterns presented during the familiarization phase are expected to classify the previously unseen dot prototype as a category member more often than low distortions of the prototype which in turn should be classified as members more often than the high distortions of the prototype. The non-category distortions are expected to be classified as category members the least often. In order to address this aim, Percent Endorsed was the main dependent measure of interest. This percentage provided a measure of how often the dot patterns were classified as members of the previously seen category.

Percent Endorsed was calculated for each distortion level (Prototype, Low, High, Non-category) by counting the number of "Yes" responses for that distortion level during the test trials, dividing that number by the total number of stimuli at that level (4 for Prototype, 20 for Low, 20 for High, and 40 for Non-category), and multiplying the result by 100. A 2-way ANOVA was conducted on the Percent Endorsed data. The between subjects variable was Group (Autism vs. Control) and the within subject variable was Distortion (Prototype vs. Low vs. High vs. Non-category). Results indicated a significant main effect of Distortion, F (3, 114) = 85.30, $p < .01$. Post-hoc comparisons (Holm-Bonferroni) resulted in significant differences between all Distortion levels with Percent Endorsed being highest for the Prototype dot patterns (M = 88.13%), second highest for the Low distortion dot patterns (M = 68.25%), third highest for the High distortion dot patterns (M = 58.63%) and least for the Non-category dot patterns (M = 37.73%). All comparisons were significant at the $p < .01$ level. Results did not evidence a significant main effect of Group, F (1, 38) = 1.71, $p = .20$. In general, the Control group (M =

64.94%) did not differ from the Autism group (*M* = 61.43%) in the mean Percent Endorsed across distortion levels.

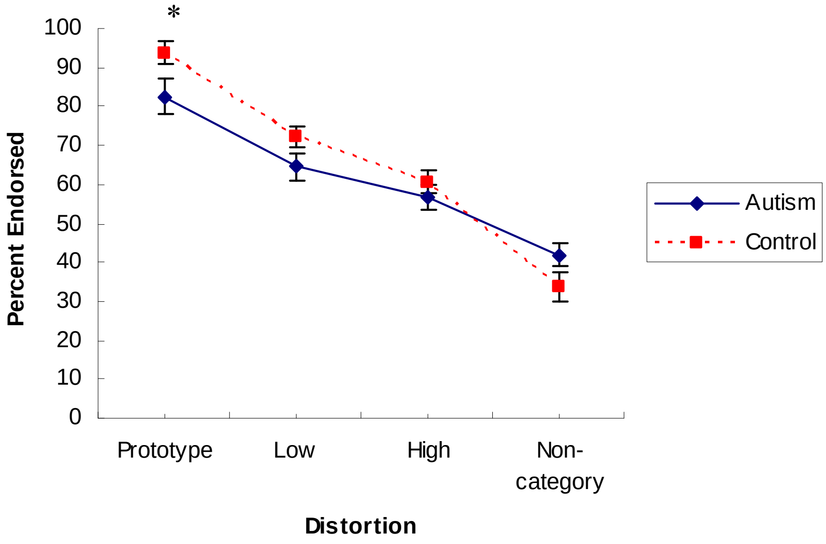


Figure 8. Mean Percent Endorsed by Distortion Level (* *p* < .05)

The Group X Distortion interaction was significant, *F* (3, 114) = 3.55, *p* < .05. The Percent Endorsed data by distortion level is presented in Figure 8. Post-hoc paired comparisons (Holm-Bonferroni) conducted separately for the Autism and Control groups resulted in significant differences between all Distortion levels for the Control group (*p* < .001) and Autism group (*p* < .05). Therefore, there was a stronger pattern of Prototype > Low > High > Non-category dot pattern Percent Endorsement for the Control group than the Autism group.

Independent samples t-tests were performed on all distortion levels to determine whether there were any group differences in the Percent Endorsed data. It can be seen in Figure 8 that the Autism (*M* = 56.75%) and Control (*M* = 60.50%) groups did not significantly differ in the percentage of High level distortions endorsed as category members, *t* = -.87, *p* = .39. There was a marginally significant difference between the groups for both the Low distortion and Non-category stimuli. The Control group (*M* = 72.00%) endorsed more Low distortions as category members than the Autism group (*M* = 64.50%), *t* = -1.72, *p* = .09. In contrast, the Control group (*M* = 33.50%) endorsed fewer Non-category stimuli as category members than the Autism group (*M* = 41.95%), *t* = 1.74, *p* = .09. The only significant result was that the Control group (*M* = 93.75%) endorsed the Prototype stimuli as category members significantly more often than the Autism group (*M* = 82.50%), *t* = -2.07, *p* < .05. Taken together, these results suggest that the Control group formed a more well-defined category and prototype of dot patterns than the Autism group during the familiarization phase as evidenced by including more category members (specifically Low distortions and Prototype dot patterns) in the learned category and excluding more Non-category dot patterns from the learned category.

In order to further examine potential differences in the formation of the entire dot pattern category, a composite score (Total Percent Correct) was calculated for each participant that consisted of the average of the participant's performance on all levels of distortion. The Total Percent correct was calculated by averaging the Percent Endorsed scores for the Low distortions, High distortions, and Prototype dot patterns and the Percent Correct score (opposite of Percent Endorsed) for the Non-category dot patterns. The Percent Correct score rather than Percent Endorsed score was used for the Non-category stimuli because a correct categorization of the Non-category stimuli resulted when the participant correctly excluded the Non-category dot pattern from the learned category. An independent samples t-test indicated that the Control group (*M* = 73.19%) correctly categorized more dot patterns than the Autism Group (65.45%), *t* = -2.82, *p* < .01. This result provides additional support for the notion that the Control group formed a more well-defined category of dot patterns than the Autism group during the familiarization phase by including more category members in the learned category and excluding more Non-category dot patterns from the learned category.

As with Experiment 1, while these analyses provide important information regarding between group differences in the Percent Endorsed data, they do not address potential differences in the range or distribution of scores between the two groups. For instance, were there more participants in the Control group who showed clear evidence of dot prototype formation? Were there more participants in the Autism group who showed clear evidence of a lack of dot prototype formation?

Figure 9 presents the distribution of performance in the dot prototype task across groups as a frequency plot of the number of participants in each group who correctly endorsed one, two three, or four of the dot prototype stimuli as category members. It can be seen that sixteen out of twenty participants in the Control group showed clear evidence of dot prototype formation by correctly endorsing the dot prototype stimuli in four out of four trials. However, only ten participants in the Autism group showed clear evidence of dot prototype formation. In contrast, one participant in the Control group and four participants in the Autism group showed clear evidence of a lack of prototype formation by correctly endorsing the dot prototype stimuli as category members in two or fewer trials. Six participants in the Autism group and three participants in the Control group correctly endorsed the dot prototype stimuli as category members in three out of four trials. Since correctly endorsing the dot prototype stimuli as category members in two out of four trials can be considered to be random or chance level performance, it is difficult to know whether endorsing the dot prototype stimuli as category members in three out of four trials is evidence of prototype formation or not. A chi-square analysis comparing the distribution of clear prototype formers (*n* = 10 in the Autism group,

$n = 16$ in the Control group) and clear non-prototype formers ($n = 4$ in the Autism group, $n = 1$ in the Control group) revealed a marginally significant association between diagnosis and prototype formation, $\chi^2(1) = 2.92$, $p = .09$. Based on the odds ratio, individuals in the Control group were 6.40 times more likely to show clear evidence of prototype formation than were individuals in the Autism group.

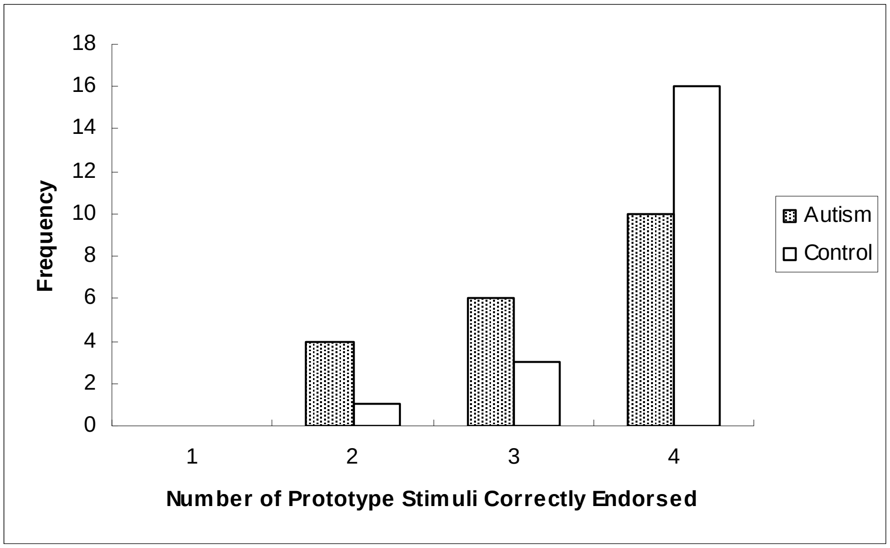


Figure 9. Distribution of Performance for the Prototype Stimuli across Groups

3.2.2 D-prime (D') Data

One potential problem with the Percent Endorsed data is that participants who had a bias towards pressing "Yes" and endorsing stimuli as category members would have high Percent Endorsed scores on the Prototype, Low, and High distortions even if they did not abstract the prototype and category of the dot patterns during the familiarization phase. In order to examine Percent Endorsed and control for response bias, D-prime (D') scores were calculated for the

Prototype, Low distortion, and High distortion stimuli. Higher D' scores are indicative of better performance.

Before calculating D', the number of Hits, Misses, False Alarms, and Correct Rejections had to be calculated. Hits (H) were defined as responses in which the participant correctly endorsed a Prototype, Low distortion, or High distortion dot pattern as a member of the previously seen category. Misses (M) were defined as responses in which the participant incorrectly rejected a Prototype, Low distortion, or High distortion dot pattern as a member of the previously seen category. False Alarms (FA) were defined as responses in which the participant incorrectly endorsed a Non-category dot pattern as a member of the previously seen category. Correct Rejections (CR) were defined as responses in which the participant correctly rejected a Non-category dot pattern as a member of the previously seen category.

D' was calculated separately for Prototype, Low distortion, and High Distortion dot patterns using the following formula:

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

A 2-way ANOVA was conducted on the D' data. The between subjects variable was Group (Autism vs. Control) and the within subject variable was Distortion (Prototype vs. Low vs. High). The D' data by distortion level is presented in Figure 10. When response bias was controlled for, results indicated a significant main effect of Distortion, $F\ (2, 76) = 80.27$, $p < .001$. Post-hoc comparisons (Holm-Bonferroni) resulted in significant differences between all Distortion levels with D' being highest for the Prototype dot patterns ($M = 2.77$), second highest for the Low distortion dot patterns ($M = .87$), and the least for the High distortion dot patterns ($M = .59$). All comparisons were significant at the $p < .001$ level. Results also evidenced a significant main effect of Group, $F\ (1, 38) = 8.21$, $p < .01$. In general, the Control group ($M =$

1.76) endorsed more Prototype, Low distortion, and High distortion dot patterns as category members than the Autism group (*M* = 1.06).

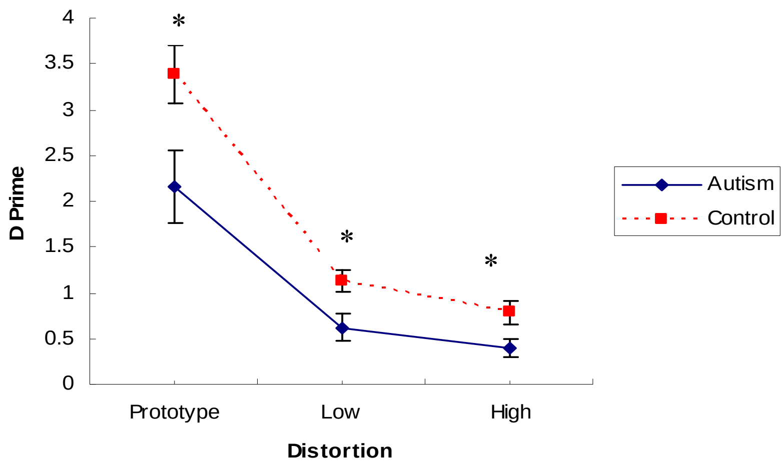


Figure 10. D-prime by Distortion Level (* *p* < .05)

The interaction was marginally significant, *F* (2, 76) = 2.93, *p* = .06. Post-hoc comparisons (Holm-Bonferroni) conducted separately for the Autism and Control groups resulted in significant differences between all Distortion levels for the Control group (*p* < .001). All differences between Distortion levels were significant for the Autism group at the *p* < .01 level except the difference between the Low and High distortion stimuli which was significant at the *p* < .05 level. Therefore, there was again a stronger pattern of Prototype > Low > High D' for the Control group than the Autism group.

Independent samples t-tests were performed on all distortion levels to determine whether there were any group differences in the D' data. It can be seen in Figure 10 that when response bias was controlled for, the Control group (*M* = 3.38 and *M* = 1.12 and *M* = .79) endorsed significantly more Prototype, Low distortion and High distortion dot patterns as category members than the Autism group (*M* = 2.16 and *M* = .62 and *M* = .40) (*t* = -2.40, *p* < .05 for Prototype dot patterns, *t* = -2.65, *p* < .05 for Low distortion dot patterns, and *t* = -2.38, *p* < .05 for High distortion dot patterns). Therefore, once response bias was controlled for, the Control group showed significantly better performance for both Low and High distortions than the Autism group. This indicates that the Autism group was more likely to have a response bias leading to only marginally significant results for the Percent Endorsed data for the Low and High distortions. These results provide stronger evidence that the Control group formed a more well-defined category of dot patterns during the familiarization phase than the Autism group.

3.2.3 Relationship between Prototype Formation or Category Formation and Other Abilities

The second aim of Experiment 2 was to determine whether dot prototype (Percent Endorsed and D' for the Prototype dot patterns) or category formation ability (D' for Low and High distortions) is related to measures of intelligence, low-level perceptual processing, or the social, communication, or behavioral symptoms of autism. Correlations between measures of prototype and category formation and measures of intelligence (VIQ, PIQ, and FSIQ), low-level perceptual processing (K-SNAP Gestalt Closure T-Score), and the social, communication, and behavioral symptoms of autism (ADOS Social Interaction Total Score, ADOS Communication Total Score, ADOS Social Interaction and Communication Total Score, and ADOS Stereotyped Behaviors and Restricted Interests Total Score) were calculated. The correlations were calculated separately for the Autism group and the Control group since different variables may be related to performance in each group. The correlations between performance on the dot prototype task and the other measures are presented in Table 8.

Table 8: Correlations Between Dot Prototype Task Performance and Measures of Intelligence, Symptoms of Autism, and Low-level Perceptual Processing

Prototype Percent Endorsed	Autism	Control
VIQ	.19	-.17
PIQ	.48*	-.33
FSIQ	.57**	-.29
ADOS Social Interaction Total	-.14	
ADOS Communication Total	-.12	
ADOS Social Interaction and Communication Total	-.15	
ADOS Restricted Behavior and Stereotyped Interests Total	-.03	
K-SNAP Gestalt Closure T-Score	.66**	-.10

Prototype D’	Autism	Control
VIQ	.08	-.10
PIQ	.63***	-.40
FSIQ	.63***	-.31
ADOS Social Interaction Total	-.31	
ADOS Communication Total	-.33	
ADOS Social Interaction and Communication Total	-.36	
ADOS Restricted Behavior and Stereotyped Interests Total	-.03	
K-SNAP Gestalt Closure T-Score	.72***	-.10

Low Distortion D’	Autism	Control
VIQ	-.01	-.26
PIQ	.37	-.26
FSIQ	.34	-.28
ADOS Social Interaction Total	-.40*	
ADOS Communication Total	-.43*	
ADOS Social Interaction and Communication Total	-.47**	
ADOS Restricted Behavior and Stereotyped Interests Total	-.02	
K-SNAP Gestalt Closure T-Score	.22	-.24

High Distortion D’	Autism	Control
VIQ	.08	-.37
PIQ	.37	-.23
FSIQ	.42*	-.31
ADOS Social Interaction Total	-.29	
ADOS Communication Total	-.43*	
ADOS Social Interaction and Communication Total	-.41*	
ADOS Restricted Behavior and Stereotyped Interests Total	-.29	
K-SNAP Gestalt Closure T-Score	.32	-.25

*** $p < .01$
** $p < .05$
* $p < .08$

It can be seen that in the Autism group, the Percent Endorsed score and the D’ for the Prototype dot patterns was positively related to PIQ ($r = .48$, $p < .05$; $r = 63$, $p < .01$), FSIQ ($r = .57$, $p < .01$; $r = .63$, $p < .01$), and the K-SNAP Gestalt Closure T-Score ($r = .66$, $p < .01$; $r = .72$, $p < .01$). These correlations suggest that in the Autism group, individuals who were able to form a prototype of the dot patterns had higher IQs and better perceptual abilities than those who were unable to form a prototype of dot pattern information. They also suggest that individuals with autism who were able to form a dot pattern prototype evidenced a greater ability to engage in global processing or had less of a local processing bias than those who were unable to form a prototype of dot pattern information.

Regarding category formation ability, D’ scores for the Low distortions were significantly correlated with the ADOS Social Interaction and Communication score in the Autism group, $r = -.47$, $p < .05$. The correlation for the High distortions was marginally significant, $r = .41$, $p = .07$. This suggests that individuals with autism who were more successful in correctly endorsing Low and High distortion dot patterns as category members had fewer social and communication deficits. None of the correlations reached significance for the Control group.

3.2.4 Eye-tracking Results

The third aim of Experiment 2 was to use eye-tracking technology to investigate what areas of the stimulus and/or dot pattern typically developing individuals and individuals with autism attend to or look at when forming a prototype of dot patterns. Of the 20 individuals with autism and 20 control individuals, 15 individuals in each group were included in the eye-tracking analyses. Five participants in each group were excluded due to poor eye-tracking data (e.g., poor calibration or lack of accurate eye-tracking). As with the full participant set, no significant differences were found between the two groups on age, FSIQ, VIQ, or PIQ.

Of interest was whether the Autism and Control groups differed in the mean number of dots that were fixated upon or the proportion of time that they spent looking at the dot patterns (% LT) during the familiarization trials. Differences in these measures could provide important information about *why* the Autism group performed more poorly on the dot prototype task. For example, if the Autism group spent less time looking at the dot patterns and more time looking at the background, they would be less likely to form a prototype or dot pattern category during the familiarization phase. Similarly, if the Autism Group engaged in localized processing involving focusing on or looking at fewer dots, they may be less likely to form a prototype of the entire dot pattern.

As stated above, it was important to determine whether the Autism and Control groups differed in the amount of time that they spent looking at the Figure AOI (dot pattern) vs. the Stimulus AOI (dot pattern and background). The dependent measure of interest was the % LT for the Figure AOI (% Figure). To calculate the % LT, the observation length or the total amount of time spent looking at each AOI (i.e., Figure and Stimulus) was summed across all of the familiarization trials. The % Figure was then calculated by dividing the total amount of time the participant spent looking at the Figure by the total amount of time spent looking at the Stimulus and multiplying the result by 100. An independent samples t-test determined that the Autism group (M = 98.71%) and Control group (M = 99.60%) did not differ in the percentage of time that they spent looking at the dot patterns, t = -1.65, p = .11. Therefore, the difference between the Autism group and Control group in prototype formation ability was not due to a differential amount of time spent looking at the dot patterns.

To address whether the groups differed in the number of dots that were fixated upon during the familiarization trials, the dependent measure of interest was the mean percentage of dots fixated upon (% Dots). The % Dots was used as the dependent measure rather than the number of dots, because some dot patterns had fewer than nine dot AOIs due to the location of the dots in the dot pattern (see the Methods section for a review of the AOI definitions). An independent samples t-test determined that the Autism group ($M = 28.99\%$) and Control group ($M = 26.02\%$) did not differ in the percentage of dots that they fixated upon during the familiarization trials, $t = .57$, $p = .57$. In fact, neither group directly looked at more than two to three out of nine dots on average. This result indicates that both groups focused on only a few dots on average when viewing the familiarization trials. Therefore, the difference between the Autism and Control groups in prototype formation ability was also not due to differences in the number of dots that were directly fixated upon during the familiarization trials.

3.2.5 Subset Analyses

The final aim of Experiment 2 was to examine individual differences in the ability to abstract prototypes. More specifically, it was aimed to determine whether there was a subset of individuals with autism who were able to successfully form a dot pattern prototype. Of particular interest is whether individuals with autism who were able to successfully form a dot pattern prototype differed from those who performed poorly on the dot prototype task on measures of intelligence, low-level perceptual processing, symptoms of autism, or eye-tracking measures.

To this end, the 20 participants with autism were grouped into two subgroups, prototype formers and non-prototype formers. Prototype formers were defined as individuals who endorsed the prototype as a category member in three or more of the four test trials (*n* = 16 for most measures, *n* = 11 for eye-tracking measures). Non-prototype formers were defined as individuals who endorsed the prototype as a category member in two or fewer test trials (*n* = 4). The means and standard deviations for the measures of intelligence, low-level perceptual processing, symptoms of autism, and eye-tracking for the prototype formers and non-prototype formers are presented in Table 9. Due to the small sample size for the non-prototype formers, formal statistical tests could not be performed on this data.

Table 9: Means and Standard Deviations for Measures of Intelligence, Symptoms of Autism, Low-level Perceptual Processing, and Eye-tracking for Prototype Formers and Non-prototype Formers for the Dot Prototype Experiment

Variable	Prototype Formers (*n* = 16) *M* (*SD*)	Non-prototype Formers (*n* = 4) *M* (*SD*)
VIQ	109.81 (9.50)	103.50 (10.88)
PIQ	111.62 (12.90)	107.00 (10.95)
FSIQ	111.75 (7.36)	105.75 (7.93)
ADOS Social Interaction Total	9.00 (1.59)	8.75 (.50)
ADOS Communication Total	5.31 (1.14)	5.00 (1.41)
ADOS Social Interaction and Communication Total	14.31 (1.83)	13.75 (1.89)
ADOS Restricted Behavior and Stereotyped Interests Total	2.19 (1.58)	2.75 (.96)
K-SNAP Gestalt Closure T-Score	59.13 (8.07)	51.50 (8.35)
	Prototype Formers (*n* = 11) *M* (*SD*)	Non-prototype Formers (*n* = 4) *M* (*SD*)
% Figure	98.95 (1.96)	98.06 (2.26)
% Dots	30.91 (20.05)	23.71 (10.13)

As can be seen in Table 9, the differences between the two groups using these criteria were quite small. Similar to the Experiment 1, a limitation of using the criteria of three out of four trials is that, since choosing the prototype as a category member in two out of four trials can be considered to be random or chance level performance, it is difficult to know whether choosing the prototype as a category member in three out of four trials is evidence of prototype formation or not. Therefore, a second set of subgroups were formed using a more stringent definition of prototype former. For these subgroups, prototype formers were defined as individuals who endorsed the prototype as a category member in all test trials (four out of four or 100%). Non-prototype formers were defined the same way as in the first set of subgroups. Individuals who endorsed the prototype as a category member in three out of four trials were excluded from these subgroups.

The means and standard deviations for the measures of intelligence, low-level perceptual processing, symptoms of autism, and eye-tracking for the prototype formers (*n* = 10 for most measures, *n* = 8 for eye-tracking measures) and non-prototype formers (*n* = 4) using a more stringent classification criteria are presented in Table 10. Again, due to the small sample size for the non-prototype formers, formal statistical tests could not be performed on this data. However, an examination of the group means indicated that the prototype formers had higher FSIQ (*M* = 115.30) and PIQ (*M* = 118.30) scores than non-prototype formers (FSIQ *M* = 105.75; PIQ *M* = 107.00). These results parallel the correlational results and suggest that individuals with autism who were able to form a prototype of the dot patterns had better perceptual abilities and higher IQ scores than those who were unable to form a prototype of dot pattern information. Prototype formers (*M* = 63.70) also had a higher K-SNAP Gestalt Closure T-scores than non-prototype formers (*M* = 51.50). These results also parallel the correlational results and suggest that individuals with autism who were able to form a dot pattern prototype evidenced a greater ability to engage in global processing or had less of a local processing bias than those who were unable to form a prototype of dot pattern information.

Table 10: Means and Standard Deviations for Measures of Intelligence, Symptoms of Autism, Low-level Perceptual Processing, and Eye-tracking for Prototype Formers and Non-prototype Formers for the Dot Prototype Experiment using Stringent Criteria

Variable	Prototype Formers (n = 10) *M* (*SD*)	Non-prototype Formers (n = 4) *M* (*SD*)
VIQ	109.30 (7.70)	103.50 (10.88)
PIQ	118.30 (7.66)	107.00 (10.95)
FSIQ	115.30 (6.55)	105.75 (7.93)
ADOS Social Interaction Total	8.60 (1.35)	8.75 (.50)
ADOS Communication Total	4.90 (.88)	5.00 (1.41)
ADOS Social Interaction and Communication Total	13.50 (1.65)	13.75 (1.89)
ADOS Restricted Behavior and Stereotyped Interests Total	2.40 (1.58)	2.75 (.96)
K-SNAP Gestalt Closure T-Score	63.70 (4.57)	51.50 (8.35)
	Prototype Formers (n = 8) *M* (*SD*)	Non-prototype Formers (n = 4) *M* (*SD*)
% Figure	98.61 (2.24)	98.06 (2.26)
% Dots	28.95 (16.11)	23.71 (10.13)

** $p < .01$
* $p < .05$

One remaining question is whether individuals with autism who were able to form a prototype of the dot patterns also formed more well-defined categories of dot patterns. In other words, did the prototype formers endorse more High and Low distortions as category members and exclude more Non-category stimuli as category members of the learned dot pattern category. To address this question, individuals with autism were again divided into subgroups using the stringent definition of prototype former (i.e., 100% prototype stimuli endorsed as category members). All other individuals with autism were considered to be non-prototype formers. These definitions resulted in larger subgroups and allowed for formal statistical analyses.

Table 11 shows the means and standard deviations for the measures of intelligence, low-level perceptual processing, and symptoms of autism for prototype formers and non-prototype formers using these criteria. Independent samples t-tests produced similar results as the previous analyses with prototype formers having significantly higher FSIQs, PIQs, and K-SNAP Gestalt Closure T-Scores than non-prototype formers. However, these results were more significant due to increased sample sizes and power ($t = 3.49$, $p < .01$ for FSIQ; $t = 3.43$, $p < .01$ for PIQ; $t = 4.62$, $p < .001$ for K-SNAP Gestalt Closure T-Score).

Table 11: Means and Standard Deviations for Measures of Intelligence, Symptoms of Autism, and Low-level Perceptual Processing for Prototype Formers and Non-prototype Formers for the Dot Prototype Experiment using Stringent Criteria (All Participants)

Variable	Prototype Formers ($n = 10$) *M* (*SD*)	Non-prototype Formers ($n = 10$) *M* (*SD*)
VIQ	109.30 (7.70)	107.80 (11.98)
PIQ *	118.30 (7.66)	103.10 (11.75)
FSIQ *	115.30 (6.55)	105.80 (5.57)
ADOS Social Interaction Total	8.60 (1.35)	9.30 (1.49)
ADOS Communication Total	4.90 (.88)	5.60 (1.35)
ADOS Social Interaction and Communication Total	13.50 (1.65)	14.90 (2.73)
ADOS Restricted Behavior and Stereotyped Interests Total	2.40 (1.58)	2.20 (1.87)
K-SNAP Gestalt Closure T-Score **	63.70 (4.57)	51.50 (7.00)

** $p < .001$
* $p < .01$

The Percent Endorsed and D' data for prototype formers and non-prototype formers is presented in Figures 11 and 12. The Control group data is also included in the figures as a comparison. Independent samples t-tests resulted in marginally significant differences between the groups in the Percent Endorsed data for Low distortions and Non-category members. Prototype formers (*M* = 70.00%) endorsed more Low distortions as category members than non-prototype formers (*M* = 59.00%), *t* = 1.71, *p* = .11. Prototype formers (*M* = 36.25%) also endorsed fewer Non-category members as members of the learned category than non-prototype formers (*M* = 47.65%), *t* = -1.98, *p* = .06. However, when response bias was controlled for (i.e., D' data), prototype formers (*M* = .94) endorsed significantly more Low distortions as category members than non-prototype formers (*M* = .30), *t* = 2.43, *p* < .05. The results for the High distortions was only marginally significant with prototype formers (*M* = .59) endorsing significantly more High distortions as category members than non-prototype formers (*M* = .21), *t* = 1.98, *p* = .06.

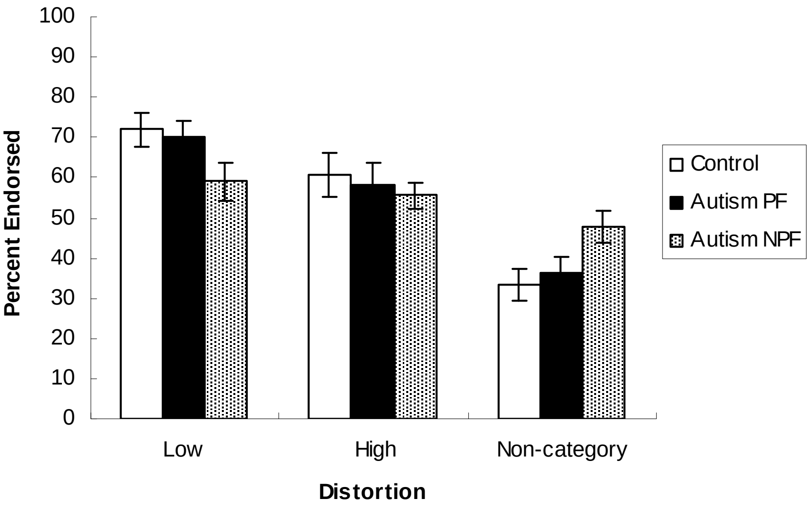


Figure 11. Mean Percent Endorsed by Distortion Level for Prototype Formers and Non-prototype Formers with the Control Group as a Comparison

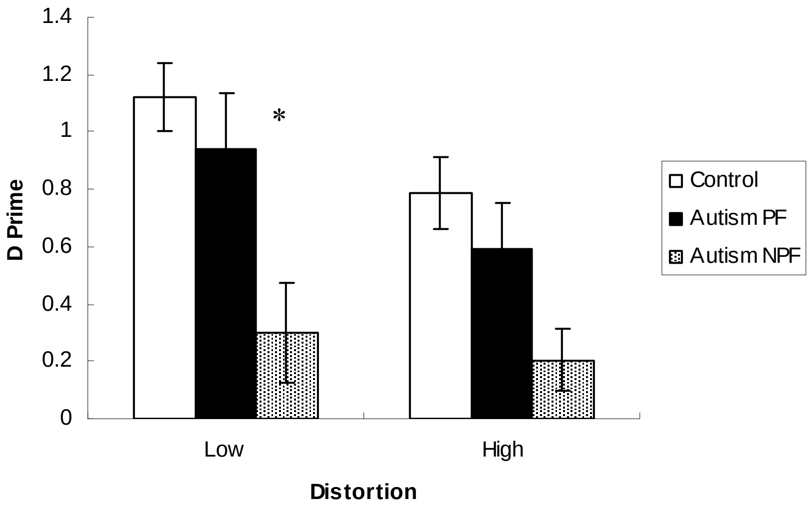


Figure 12. D-prime by Distortion Level for Prototype Formers and Non-prototype Formers with the Control Group as a Comparison (* *p* < .05)

Taken together, these results suggest that within the Autism group, when individuals with autism were able to form a prototype of dot patterns, they also formed a significantly more well-defined category of dot patterns. This result was evidenced by including more Low and High distortions in the learned category and excluding more Non-category members from the category. In fact, independent samples t-tests indicated that even though their scores were somewhat lower, the data for the prototype formers was not significantly different from the control data for Percent Endorsed or D’ for any level of distortion. Therefore, there was a subgroup of ten individuals with autism (half of the participants) who were able to successfully form a prototype and category of dot pattern information. As stated above, these individuals had higher IQs, better perceptual abilities, and may have had a greater ability to engage in global processing or may have had less of a local processing bias than those who were unable to form a prototype of dot pattern information. It is important to note that even though half of the individuals with autism (10 out of 20) were able to abstract the dot pattern prototype, almost all of the participants in the Control group (16 out of 20) were able to do so successfully.

3.3 DISCUSSION

The first aim of Experiment 2 was to investigate whether individuals with autism, in contrast to typically developing individuals, experience difficulty abstracting prototypes of dot pattern information. Results indicated that across both groups, participants showed a pattern of results where the percent of dot patterns endorsed as category members was highest for the Prototype dot patterns (*M* = 88.13%), second highest for the Low distortion dot patterns (*M* = 68.25%), third highest for the High distortion dot patterns (*M* = 58.63%) and least for the Non-category dot patterns (*M* = 37.73%). As was hypothesized, the Control group results paralleled those from Kéri, Kálmán, et al. (2001) in that the they correctly categorized the Prototype dot patterns more often than the Low distortions which were in turn correctly categorized more often than the High distortions. The Non-category dot patterns were endorsed as members of the learned category the least often.

This pattern of endorsement was also evident in the Autism group, but to a lesser extent. Even so, there was a significant difference between all levels of distortion for the Autism group. The only between group difference that emerged was for the Prototype stimuli indicating that the Control group correctly endorsed the Prototype stimuli as category members more often than the Autism group. In fact, sixteen out of twenty participants in the Control group showed clear evidence of dot prototype formation by correctly endorsing the dot prototype stimuli as category members in four out of four trials while only ten participants in the Autism group showed clear evidence of dot prototype formation. There were also marginally significant differences in the Percent Endorsed for the Low distortions and Non-category members with the Autism group correctly endorsing fewer Low distortions and incorrectly endorsing more Non-category members than the Control group. However, when response bias was controlled for using D’, the Autism group showed significantly poorer performance for the Prototype dot patterns, Low distortion, and High distortions than the Control group.

Taken together, the results suggest that the Control group formed a more well-defined category and prototype of dot patterns than the Autism group during the familiarization phase of the experiment by including more category members in the learned category and excluding more non-category patterns from the learned category. In contrast, the Autism group evidenced “fuzzier boundaries” and included more non-category patterns into the learned category. Therefore, the second hypothesis was partially supported and the third hypothesis was supported in that even though the participants in the Autism group showed the same pattern of results as the Control group, they evidenced more difficulty with correctly categorizing all levels of distortion when response bias was taken into account.

While no specific hypotheses were made, the second aim was to determine whether dot prototype formation ability was related to measures of intelligence, low-level perceptual processing, or the social, communication, or behavioral symptoms of autism. As with Experiment 1, none of the correlations reached significance for the Control group indicating that performance on the dot prototype task was not related to intelligence or low-level perceptual processing. The Percent Endorsed and D’ scores for the Prototype dot patterns were positively related to FSIQ, PIQ, and the K-SNAP Gestalt Closure T-Scores in the Autism group. These correlations suggest that individuals with autism who were able to form a prototype of the dot patterns had higher IQ scores and better perceptual abilities. These individuals may have also had stronger global processing skills, less “weak central coherence”, or less of a local processing bias than those who were unable to form a prototype of dot pattern information. Regarding category formation ability, correlations between D’ scores and the ADOS Social Interaction and Communication score was significant for Low distortions and marginally significant for High distortions. These results suggest that individuals with autism who were more successful in correctly endorsing Low and High distortion dot patterns as category members had fewer social and communication deficits. Potential significance of these results will be discussed in detail in the General Discussion.

The third aim was to use eye-tracking technology to investigate what areas of the stimulus and/or dot pattern typically developing individuals and individuals with autism attend to or look at when forming a prototype of dot patterns. Eye-tracking data was collected during the familiarization trials in order to address *why* the Autism group performed more poorly on the dot prototype task. Differences in the mean number of dots that were fixated upon or the proportion of time that the participants spent looking at the dot patterns during the familiarization trials may provide potential explanations for these results. For example, if the Autism group spent less time looking at the dot patterns and more time looking at the background, they would be less likely to form a prototype or dot pattern category during the familiarization phase. Similarly, if the Autism Group engaged in localized processing involving focusing on or looking at fewer dots, they may be less likely to form a prototype of the entire dot pattern.

Examination of eye fixation patterns indicated that, as hypothesized, the Autism and Control groups did not differ in the amount of time spent looking at the dot patterns. Therefore, the difference between the Autism group and Control group in prototype formation ability was not due to a differential amount of time spent looking at the dot patterns during the familiarization trials. It was hypothesized that the participants in the Control group would look at all or most of the dots in the dot patterns during the familiarization phase while the participants in the Autism group would look at fewer dots in the dot patterns. These hypotheses were not supported in that both groups looked at approximately two to three of the nine dots on average. Therefore, the difference between the Autism and Control groups in dot prototype formation ability was not due to differences in the number of dots that were directly fixated upon during the familiarization trials.

The final aim was to examine individual differences in the ability to abstract prototypes in individuals with autism. A closer examination of individual participant's data in the Autism group indicated that there was a subset of individuals with autism who were able to form a prototype of dot pattern information. A generous definition of prototype former (correctly endorsed the prototype dot patterns as category members in three or four out of four trials) identified sixteen individuals with autism who performed well on the dot prototype task while a stringent definition of prototype former (correctly endorsed the prototype dot patterns as category members in four out of four trials) identified ten individuals with autism with intact dot prototype formation abilities. An important question is whether individuals with autism who were able to form a prototype of dot pattern information differed from those who were unable to do so successfully. Results indicated that the individuals with autism who performed best on the dot prototype formation task had higher FSIQ, PIQ, and K-SNAP Gestalt Closure T-scores than those who performed poorly on the dot prototype task. These results parallel the correlational results and suggest that individuals with autism who were able to form a prototype of the dot patterns had higher IQs and better perceptual abilities. These individuals may have also had stronger global processing skills, less “weak central coherence”, or less of a local processing bias than those who were unable to form a prototype of dot pattern information. As with the correlational results, potential significance of these results will be discussed in the General Discussion.

Another question was whether individuals with autism who were able to form a prototype of the dot patterns also formed more well-defined categories of dot patterns. It was found that individuals with autism who formed the prototype did form a significantly more well-defined category of dot patterns as was evidenced by including more Low and High distortions in the learned category and excluding more Non-category members from the category. In fact, even though their scores were somewhat lower, individuals with autism who were prototype formers did not significantly differ from the Control group on Percent Endorsed or D’ for any level of distortion. Thus, there was a subgroup of ten individuals with autism (half of the participants) who were able to successfully form a prototype and category of dot pattern information. As stated above, these individuals had higher IQs, better perceptual abilities, and may have had a greater ability to engage in global processing or may have had less of a local processing bias than those who were unable to form a prototype of dot pattern information. It is important to note that even though half of the individuals with autism (10 out of 20) were able to abstract the dot pattern prototype, almost all of the participants in the Control group (16 out of 20) were able to do so successfully. Therefore, even though a subgroup of individuals with autism performed well on the dot prototype task, there were significantly fewer than in the Control group.

4.0 GENERAL DISCUSSION

This study was the first to examine prototype formation abilities in individuals with autism with both social and non social stimuli. Regarding the social stimuli, it was the first to use natural faces to study prototype formation. This is important because natural faces provide a close replication of the facial information that is abstracted in real life. For the non-social stimuli, this study was the first to use dot patterns, an artificial category that has been widely used to study prototype formation in a variety of populations from infants (Bomba & Siqueland, 1983; Younger & Gotlieb, 1988) to adults with Alzheimer's disease (Kéri, Kálmán, et al., 2001) or schizophrenia (Kéri, Kelemen, et al., 2001). Since the general population does not have prior experience with dot patterns, using dot patterns to study prototype formation allows one to study the pure process of prototype formation without possible confounds of stimulus experience.

A unique aspect of this study is that it was the first to use eye-tracking technology to provide information about what individuals with autism are looking at when forming prototypes or categories of social and non-social information. Another unique aspect of this study was that performance on the face and dot prototype studies were studied in association with measures of intelligence, symptoms of autism, and low-level perceptual skills. As a result, the study was able to address both *if* individual with autism have deficits in prototype formation and *why* they may have these deficits. This study was also one of few studies to take into account the variability in performance in individuals with autism and examine individual and subgroup differences in performance on the prototype formation tasks.

The results indicated that individuals with autism had difficulty forming prototypes of both faces and dot patterns. Interestingly, the individuals with autism had more difficulty with the face prototype task than the dot prototype task. The dot prototype study also provided evidence that the individuals with autism had “fuzzy category boundaries.” In other words, they incorrectly excluded more members from the learned category and incorrectly included more non-members into the learned category. In the face prototype study, poor performance was found to be related to a higher number of stereotyped behaviors and restricted interests, while in the dot prototype study, poor performance was found to be related to lower IQs, worse perceptual skills, and more social and communication deficits. Eye-tracking data did not reveal any between group differences in the amount of time spent looking at the faces or dot patterns during the familiarization trials.

The remainder of this paper will relate the results of the current study to the previous literature on prototype formation and categorization and describe consistencies and inconsistencies with previous results. Possible explanations for the difficulties that the individuals with autism had with prototype and category formation in addition to possible explanations for success on the face and dot prototype studies in a subgroup of individuals with autism will then be discussed. Following these explanations, limitations of the current study and future research directions will be suggested.

4.1 PROTOTYPE AND CATEGORY FORMATION

Prior studies on prototype formation and categorization in individuals with autism have had mixed results with some researchers finding a deficit or differences in prototype formation and/or categorization (Gastgeb et al., 2006, 2009; Klinger & Dawson, 1995, 2001; Klinger et al., 2006; Plaisted, 2000) and others concluding that prototype formation and/or categorization is intact (Molesworth et al., 2005, 2008). It has been shown that while individuals with autism can successfully categorize on the basis of simple definitive features when the task involves simple and typical objects, they have difficulty categorizing when categorization is based on more complex/less perceptually apparent features or involves less typical objects (Gastgeb et al., 2006; Klinger & Dawson, 1995; Plaisted, 2000).

It has been argued that the "intact prototype formation" results found by Molesworth et al. (2005, 2008) may be due to participant variables (inclusion of high-functioning individuals with autism and Asperger's disorder in the studies) or methodological variables (lack of subtle quantitative variations in features) (Gastgeb et al., 2009). In other words, the autism group may not have formed a prototype but may have shown good performance by memorizing the values of the features that varied or focusing on one feature and basing their decisions on the variation in that feature rather than the entire stimulus. The current study improved upon prior studies by including only high-functioning adults with autism and using more subtle, quantitative spatial variations when designing the face and dot pattern stimuli. Another strength of the current study was that the mean prototype values for the faces and prototype stimuli for the dots were *never* seen by the participants during the familiarization phase. Therefore, memorization of facial features or dot patterns was unlikely to falsely improve performance during the test phase.

The results of the face prototype experiment are consistent with and closely parallel Gastgeb et al.'s (2009) prior study on face prototype formation using line drawings of faces. In fact, the mean prototype scores for the Control (*M* = 72.5%) and Autism groups (*M* = 50.83%) for the Wide condition in the current study were very similar to the percentages of adults in the Control (78%) and Autism groups (55%) who chose the prototype as more familiar than the modal face in the 2009 study. The percentages are slightly lower in the current study, but this is likely due to the larger number of test trials or the use of natural faces that include more subtle quantitative variation rather than line drawings. These differences made prototype formation in the current study slightly more difficult than in previous studies. The lack of group differences in the Narrow condition highlights the role that subtlety of the quantitative spatial variation of the features plays in the ability to form a prototype. It is possible that the differences in the spatial variations in the Narrow condition were *too* subtle and were indistinguishable to all participants.

The results of the dot prototype experiment for the Control group are consistent with previous research by Keri and colleagues and led to a similar pattern of results with the Prototype stimuli being correctly endorsed as category members most often, Low distortions second, High distortions third, and Non-category members the least often (Kéri et al., 1999; Kéri, Kálmán, et al., 2001; Kéri, Kelemen, et al., 2001). In contrast, the results for the Autism group revealed poorer prototype formation abilities and weaker category structures thus supporting the previous findings of Klinger and Dawson (2001), Klinger et al. (2006), and Plaisted (2000) indicating a deficit in prototype formation of non-face information (e.g., animal-like stimuli) in individuals with autism.

The results, however, contradict prior research by Molesworth et al. (2005, 2008) that found intact prototype formation abilities in individuals with autism. It is likely that the methodological differences between the current study and Molesworth's studies, especially the use of more complex quantitative spatial variation in the current study that cannot be categorized or abstracting by using simple rules or by focusing on one feature, led to these differences in results.

The results from the dot prototype study also extended previous findings in gender and object categorization indicating that individuals with autism have "fuzzy category boundaries" and have difficulty categorizing less typical members of natural object and gender categories and extended these results to artificial categories such as dot patterns (Gastgeb et al., 2006; Strauss et al., in submission). In comparison to the Control group, individuals with autism included more Non-category dot patterns into the learned category and excluded more Low and High distortion dot patterns from the learned category.

4.2 POTENTIAL EXPLANATIONS FOR DIFFICULTIES WITH PROTOTYPE AND CATEGORY FORMATION IN INDIVIDUALS WITH AUTISM

In addition to determining whether individuals with autism have a deficit in prototype and category formation, it is important to determine *why* individuals with autism have difficulty with prototype and category formation. The results of Experiment 1 could be explained as a generalized difficulty in processing faces, since it is well known that individuals with autism have deficits in face recognition, gender categorization, and emotion recognition (e.g., Behrmann et al., 2006; Best, Minshew, & Strauss, 2010; Best, Strauss, Newell, & Minshew, in prep; Celani, Battacchi, & Arcidiacono, 1999; Deruelle, Rondan, Gepner, & Tardif, 2004; Klin, Sparrow, de

Bildt, Cicchetti, Cohen, & Volkmar, 1999; Lahaie, Mottron, Arguin, Berthiaume, Jemel, & Saumier, 2006; Rump, Giovannelli, Minshew, & Strauss, 2009). However, since the results of Experiment 2 demonstrated prototype formation and categorization difficulties with non-facial stimuli, more general explanations need to be explored.

One possibility is that individuals with autism do not pay sufficient attention to stimuli despite whether they are faces or objects. However, the eye-tracking data suggests that this is not the case. For both studies, the individuals with autism did not differ from the Control group in the percentage of time they spent looking at the stimuli in general or to the relevant features. Therefore, prototype formation and categorization difficulties cannot be accounted for by an overall lack of attention to the stimuli or the relevant information.

Even though there were no overall differences in attention to the stimuli, there were some interesting differences in the way in which the individuals with autism distributed their attention to the facial information during the familiarization phase. Despite the fact that the individuals with autism spent more time looking at the eyes than any other feature of the face, they spent less time looking at the eyes and more time looking at the mouths than the Control group. These results are consistent with other eye-tracking studies that suggest individuals with autism devote less attention to the eye region than do control individuals (e.g., Klin et al., 2002; Norbury et al., 2009; Pelphrey et al., 2002). However, the general pattern of attention to the faces for both groups was similar suggesting that differential attention to features does not explain the difficulty that the individuals with autism had in the abstraction of facial prototypes. Similarly, the eye-tracking results from the dot pattern study revealed common attentional patterns between the two groups. Therefore, prototype formation and categorization difficulties cannot be accounted for by differential attention to features or different attentional patterns to the stimuli.

Difficulties in prototype formation and categorization in individuals with autism may also be related to differences in the way in which individuals with autism cognitively process information. Two theories that address potential differences in perceptual processing are weak central coherence (Frith & Happé, 1994) and enhanced perceptual functioning (Mottron et al., 2006). According to the weak central coherence theory, individuals with autism lack the tendency to draw together diverse information to construct higher level meaning within context, prefer parts over wholes, have a local processing bias, and focus on details (Frith & Happé, 1994). It is thought that this type of processing is the automatic spontaneous processing style of individuals with autism. The enhanced perceptual functioning theory differs from the weak central coherence theory in that it posits that individuals with autism *prefer* local processing but have the ability to process items globally when required to do so (Mottron et al., 2006). If individuals with autism show weak central coherence or enhanced perceptual functioning, this would likely affect their ability to form a prototype or categorize information.

The correlations between performance on the face and dot prototype tasks and measures of intelligence, symptoms of autism, and low-level perceptual processing in the individuals with autism provide some support for these explanations. Individuals with autism who showed evidence of a lack of prototype formation on the face prototype task had lower scores on the K-SNAP Gestalt Closure task than those who performed well on the face prototype task. On the dot prototype task, individuals with autism who had lower Percent Endorsed and D' scores for the Prototype dot patterns had lower PIQs and K-SNAP Gestalt Closure T-Scores than those who had higher scores. This suggests that individuals with autism who performed poorly on the face and dot prototype tasks may have had weaker global processing skills, weaker central coherence, more of a local processing bias, and/or weaker general perceptual processing abilities than those who were able to perform the tasks successfully which may have negatively affected their ability to form a prototype of facial and dot pattern information.

Individuals with autism who showed evidence of a lack of prototype formation on the face prototype formation task also had more restricted and repetitive behaviors and interests as measured by the ADOS than those who performed well on the face prototype task. This correlation suggests that perhaps individuals with autism who tend to focus intensely on details, parts or irrelevant aspects of objects, or topics of interest may be more likely to focus on specific aspects of the face rather than the whole face which would negatively affect prototype formation.

The correlational data also revealed some interesting relationships between the social and communication symptoms of autism and performance on the dot prototype task. Individuals with autism who had lower D' scores and poorer categorization ability (e.g., fuzzier category boundaries) had more social and communication deficits as measured by the ADOS. While these relationships are intriguing, they require further investigation before any strong conclusions can be made. The ability to efficiently categorize and reduce information by forming central representations such as prototypes is critically important in that it reduces demands on memory and underlies important abilities such as face perception, object categorization, and language. While the current study addresses difficulties with perceptual categories, it is possible that these difficulties with prototype and category formation extend beyond perceptual categories to abstract and social categories such as friendship or love. Due to the role that prototype formation and categorization have in the understanding and development of language, it is also possible that these difficulties affect the communication abilities of individuals with autism and their understanding of language. Therefore, future research should investigate whether the deficits that were found with perceptual categories in the current study extend to the formation of abstract and social concepts and understanding and production of language that may be reflected in the ADOS social and communication scores.

Due to the nature of correlations, it is not possible to determine the causality between these variables; however, it is possible that an early deficit in categorization or prototype formation may lead to difficulties in socialization and communication. An early deficit in the mechanisms used to form prototypes would result in infants having difficulty decreasing the amount of information in a complex environment and easily becoming overstimulated by sensory information. Given the complexity of social information, infants may find it more adaptive to tune out social information rather than pay attention to it. Future research on infant siblings of children with autism could address this possibility by studying prototype formation and categorization in these younger populations and determining whether infant siblings of children with autism who evidence difficulties with prototype formation or categorization are more likely to have social and communication deficits at a later age.

4.3 POTENTIAL EXPLANATIONS FOR SUCCESS WITH PROTOTYPE AND CATEGORY FORMATION IN A SUBGROUP OF INDIVIDUALS WITH AUTISM

One possible explanation for mixed results in the literature on prototype formation is the heterogenous nature of the strengths, deficits, and ability levels of individuals with autism. By examining only group differences, researchers may conclude that individuals with autism do or do not have deficits in certain skills but may be missing important subgroup or individual level differences. Even though there was an overall group level deficit in prototype formation in the individuals with autism in the current study, examining performance at the individual subject level identified a subgroup of individuals with autism who appeared to have intact prototype and category formation abilities. This was especially true in the dot prototype study in which a subgroup of ten individuals with autism performed similarly to the control group. In the face prototype study, only three individuals with autism appeared to abstract a prototype of face information.

Similar to the potential explanations for the deficits in prototype formation and categorization in individuals with autism, successful performance on the prototype tasks may also be explained by the correlations between measures of intelligence, symptoms of autism, and low-level perceptual processing. Individuals with autism who appeared to show evidence of prototype formation on the face prototype task had higher scores on the K-SNAP Gestalt Closure task than those who performed poorly on that task. On the dot prototype task, individuals with autism who had higher Percent Endorsed and D' scores for the Prototype dot patterns had higher PIQs, FSIQs, and K-SNAP Gestalt Closure T-Scores than those who had lower scores. These results suggest that individuals with autism who performed well on the face and dot prototype tasks may have had stronger global processing skills, less weaker central coherence, less of a local processing bias, and/or stronger general perceptual abilities than those who were able to perform the tasks successfully which may have positively affected their ability to perform well on the prototype tasks. Therefore, it is possible that some individuals with autism do indeed have intact prototype formation skills leading to better performance on the prototype tasks.

However, it is also possible that the individuals with autism who performed well on the prototype tasks did not actually abstract a prototype of the face or dot pattern information but instead discovered an alternative strategy to succeed on these tasks. For example, for the dot prototype task, the individuals with autism may have focused on certain subsets of dots or relational patterns rather than focusing on and abstracting a prototype of the entire dot pattern.

Since the spatial variation of the placement of the dots in the dot patterns had constraints based on probabilities, the dots tended to be in the same general area from one dot pattern to the next. Therefore, successful performance could have resulted from identifying and/or focusing on a subset pattern of dots rather than forming an overall dot pattern prototype.

The significant association between IQ and performance on the dot prototype task in individuals with autism but not in control individuals suggests that higher intelligence scores may have allowed some individuals with autism to use alternative strategies to perform well without needing to form a prototype. However, these alternative strategies were likely not *as* effective or efficient as abstracting a prototype to aid in the decision process. A close examination of the dot prototype data indicates that even though the individuals with autism who appeared to successfully form a prototype of dot pattern information did not significantly differ from the Control group in their Percent Endorsed or D' scores, their scores were somewhat lower than the scores of the Control group. Therefore, while a subgroup of individuals with autism was able to perform well on the prototype tasks; their strategies may not have been as effective or efficient.

When individuals with autism are presented with even more subtle quantitative spatial variation and complex information, these potential alternative strategies or compensatory mechanisms may be even less effective or efficient or may completely break down. In the current study, more individuals with autism showed successful performance on the dot prototype task than the face prototype task. One possible explanation for the differences in performance between the two tasks is that the individuals with autism had more difficulty with the face prototype task due to the social nature of the face stimuli. An equally possible explanation for this difference is that the more subtle and complex quantitative spatial variation that is present in faces did not allow for successful performance using the potential alternative strategies suggested above. Unfortunately, there were also a number of methodological differences between the face and dot prototype tasks that make the direct comparisons between the two tasks quite difficult. Future research should improve the ability to make direct comparisons between social and non-social prototype formation or categorization abilities by using tasks that are more methodologically equivalent in addition to using stimuli that have more similar levels of subtle quantitative spatial variation of features (e.g., faces and Greebles).

4.4 LIMITATIONS

Even though the current study expands and improves upon previous studies on prototype formation and categorization, there are some limitations that must be discussed. First, even though the sample size was adequate for group level analyses, it was too small to allow for formal statistical tests to be performed at the subgroup level. It was also too small to allow for analyses to be conducted across experiments. A second limitation is that participants in the Autism group were all high-functioning. Thus, the results may not generalize to the full spectrum of autism disorders. Another limitation that occurs in studies of cognitive abilities in high-functioning individuals with autism is that it is difficult to determine whether successful performance on the tasks reflects intact abilities or whether the individuals with autism are using alternative strategies or compensatory mechanisms to perform the tasks. A final limitation of the study is the methodological differences between the face prototype and dot prototype tasks that made between task comparisons difficult. Suggestions for future research to address these limitations are made in the following section of this paper.

4.5 FUTURE DIRECTIONS

Despite the limitations presented above, the current study was the first to examine prototype formation abilities in individuals with autism in both social and non-social domains. It was also the first study to address both *if* individuals with autism have a deficit in prototype formation in addition to *why* they may have this deficit. These results should be replicated in other large samples of individuals with autism with a wide variety of ability levels using both social and non-social stimuli. Due to the amount of variability in performance in individuals with autism, future studies of prototype formation should recruit large enough groups to allow for more thorough statistical analyses of subgroup level differences and cross-task comparisons. Future studies should also examine prototype formation in low-functioning individuals with autism to determine whether deficits in prototype formation extend to these individuals.

It was previously suggested that future research on prototype formation should improve the ability to make direct comparisons between social and non-social prototype formation or categorization abilities by using tasks that are more methodologically equivalent in addition to using stimuli that have more similar levels of subtle quantitative spatial variation of features (e.g., faces and Greebles). One way in which to make the tasks more equivalent would be to make the dot pattern stimuli larger. In the current study, participants did not have to look at more than one area of the stimulus in order to "see" the entire stimulus in their central vision. This was supported by the eye-tracking data that showed that all participants looked at few dots in each pattern during the familiarization phase. Therefore it was difficult to determine whether there were any differences in the way in which the individuals with autism looked at or processed the dot patterns. Another way to make the tasks more equivalent would be to use similar procedures for the face prototype and dot prototype tasks. For example, the dot prototype task could use the same procedure as the face prototype task in the current study. Participants could be familiarized with high distortions of the prototype dot pattern and then shown two dot patterns (a new high distortion and the prototype). They could then be asked which dot pattern is more familiar to test for prototype abstraction.

The relationships that were found between prototype formation and measures of intelligence, symptoms of autism, and low-level perceptual processing provide additional avenues for future research. Future studies should further examine the relationship between prototype formation and perceptual processing using tasks that measure weak central coherence or enhanced local processing such as the Navon task. It is important for future research to continue to distinguish whether the difficulties in prototype formation are due to a general cognitive deficit in prototype formation or whether they are due to difficulties in the perception of social and non-social information. Future studies should also further examine the relationship between prototype formation and symptoms of autism. In particular, future research should investigate whether the deficits that were found with perceptual categories in the current study extend to the formation of abstract and social concepts and understanding and production of language that may be reflected in the ADOS social and communication scores.

Even though the current study found deficits in prototype formation for social and non-social perceptual information in adults with autism, researchers have not studied the developmental trajectory of prototype formation in individuals with autism. It is possible that children with autism may have more difficulty forming a prototype than adults due to adults' increased experience with learning alternative strategies. Therefore, future studies should examine prototype formation across the lifespan to determine whether the difficulties that were found in the current study are also present in children with autism and to what extent. On a related note, if the deficits in the current study truly reflect deficits in prototype formation, individuals with autism may have deficits in prototype formation as early as infancy. As was suggested earlier, an early deficit in categorization or prototype formation may lead to difficulties in socialization and communication. Therefore, future research on infant siblings of children with autism should study prototype formation and categorization in these younger populations and determine whether infant siblings of children with autism who evidence difficulties with prototype formation or categorization are likely to have more social and communication deficits at a later age.

4.6 CONCLUSION

In conclusion, the current study was the first to examine prototype formation in social and non-social domains in individuals with autism. While there have been a limited number of studies on prototype formation in individuals with autism, the results of the current study are consistent with previous studies that have found a deficit in prototype formation. The results also fit the pattern of findings in the categorization literature that suggest that individuals with autism are able to successfully categorize when the task involves simple and typical basic level objects or when categorization can be based on definitive boundaries, features, or rules. However, they experience difficulty when categorization is more complex, involves less typical objects or fuzzy boundaries, or when it requires the perception of subtle spatial variations or comparisons to a central representation such as a prototype. The latter, more complex type of categorization is required for the successful categorization of real world natural categories.

While the current study revealed difficulties with prototype formation and categorization of two perceptual categories (faces and dot patterns), it is possible that the results are reflective of a more general difficulty with reducing information and memory load by making a summative or central representation of this information. Due to the critical role that prototype formation plays in categorization and that categorization plays in understanding the world around us from the day that we are born, a deficit in these abilities could have a major impact for real world functioning. In fact, it is possible that these difficulties may extend to the understanding of abstract social concepts such as friendship or emotions. Since social concepts are abstract, complex, and involve even more subtle variation than other natural categories, individuals with autism may have even more difficulty when required to process and categorize this type of information. An early deficit in the mechanisms used to form prototypes could result in infants having difficulty decreasing the amount of information in a complex environment and may result in them becoming overstimulated by this information, possibly even leading to avoidance of complex social information. While the current study is an important first step, many more studies need to be conducted in order to determine the exact role that prototype formation and categorization deficits play in the syndrome of autism. As such, the current study highlights the need to consider the role that cognitive processes such as prototype formation and categorization may play in the syndrome of autism in future research.

BIBLIOGRAPHY

American Psychiatric Association. (2000). *Diagnostic and Statistical Manual of Mental Disorders, 4th ed., Text Revision (DSM-IV-TR).* Washington, DC: American Psychiatric Association.

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a "theory of mind"? *Cognition, 21*, 37-46.

Behrmann, M., Avidan, G., Leonard, G. L., Kimchi, R., Luna, B., Humphreys, K., et al. (2006). Configural processing in autism and its relationship to face processing. *Neuropsychologia, 44*, 110-129.

Best, C.A., Minshew, N. J., & Strauss, M. S. (2010). Gender Discrimination of Eyes and Mouths by Inividuals with Autism. *Autism Research, 3,* 88-93.

Best, C. A., & Strauss, M. S. (2007, April). *A face in the crowd: Recognition memory for distinctive faces in infancy.* Paper presented at the biennial meeting of the Society for Research in Child Development, Boston, MA.

Best, C. A., Strauss, M. S., Newell, L. C., Gastgeb, H., & Costello, M. C. (2004, May). *Developing expertise with faces: Preschoolers' implicit recognition memory for distinctive versus typical faces* Paper presented at the biennial meeting of International Conference on Infant Studies, Chicago, IL.

Best, C. A., Strauss, M. S., Newell, L. C., & Minshew, N. J. (2005, May). *Face knowledge in individuals with autism: Abstracting specific information from faces.* Poster presented at the International Meeting for Autism Research, Boston, MA.

Best, C. A., Strauss, M. S., Newell, L. C., & Minshew, N. J. (2006). The Distinctiveness Effect: Do Individuals with Autism Develop a Face Space? Manuscript in prep.

Bomba, P. C. & Siqueland, E. R. (1983). The nature and structure of infant form categories. *Journal of Experimental Child Psychology*, 35, 294-328.

Boucher, J., & Lewis, V. (1992). Unfamiliar face recognition in relatively able autistic children. *Journal of Child Psychology and Psychiatry*, *33*, 843-859.

Cabeza, R., Bruce, V., Kato, T., & Oda, M. (1999). The prototype effect in face recognition: Extension and limits. *Memory and Cognition*, *27*, 139-151.

Celani, G., Battacchi, M. W., & Arcidiacono, L. (1999). The understanding of the emotional meaning of facial expressions in people with autism. *Journal of Autism and Developmental Disorders, 29*, 57-66.

Centers for Disease Control and Prevention (2007). Prevalence of autism spectrum disorders. *Surveillance Summaries, December. MMWR 2009*, *58*, 1-20.

Deruelle, C., Rondan, C., Gepner, B. & Tardif, C. (2004). Spatial frequency and face processing in children with autism and Asperger syndrome. *Journal of Autism and Developmental Disorders*, *34*, 199-210.

Devine, P.G., & Malpass, R.S. (1985). Orienting strategies in differential face recognition. *Personality and Social Psychology Bulletin, 11,* 33-40.

Frith, U., & Happé, F. (1994). Autism: Beyond "theory of mind". *Cognition, 50*, 115-132.

Gadow, K., Sprafkin, J., & Weiss, M., (1999). *Adult Symptom Inventory-4*. Stony Brook, NY: Checkmate Plus.

Gastgeb, H. Z., Rump, K. M., Best, C. A., Minshew, N, J, & Strauss, M. S. (2009). Prototype formation: Can individuals with autism abstract facial prototypes? *Autism Research, 2*, 279-284.

Gastgeb, H. Z., Strauss, M. S., & Minshew, N. J. (2006). Do individuals with autism process categories differently: The effect of typicality and development. *Child Development*, *77*, 1717-1729

Gauthier, I., Tarr, M. J., Moylan, J., Anderson, A. W., Skudlarski, P., & Gore, J. C. (2000). Does visual subordinate-level categorisation engage the functionally defined fusiform face area? *Cognitive Neuropsychology*, *17*, 143-163.

Goldstein, A.G., & Chance, J.E. (1980). Memory for faces and schema theory. *Journal of Psychology, 105,* 47-59.

Grandin, T. (1995). How people with autism think. In E. Schopler and G. B. Mesibov (eds.), *Learning and Cognition in Autism* (pp.137-158). New York: Plenum Press.

Hayes, B. K., & Taplin, J. E. (1993a). Development of a conceptual knowledge in children with mental retardation. *American Journal on Mental Retardation*, *98*, 293-303.

Hayes, B. K., & Taplin, J. E. (1993b). Developmental differences in the use of prototype and exemplar-specific information. *Journal of Experimental Child Psychology*, *55*, 329-352.

Hayes, B, K, & Conway, R. N. (2000). Concept acquisition in children with mild intellectual disability: Factors affecting the abstraction of prototypical information. *Journal of Intellectual & Developmental Disability, 25*, 217-234.

Hermelin, B., & O'Connor, N. (1970). *Psychological Experiments with Autistic Children*. Oxford: Pergamon Press.

Homa, D., Goldhart, B., Burruel-Homa, L., & Smith, J. C. (1993). Influence of manipulated category knowledge on prototype classification and recognition. *Memory and Cognition*, *21*, 529-538.

Homa, D., Smith, C., & Macak, C. (2001). Recognition of facial prototypes: The importance of categorical structure and degree of learning. *Journal of Memory and Language*, *44*, 443-474.

Humphreys, K. (2003). *The development of face-space: An exploration.* Unpublished doctoral dissertation, University of London, London, England.

Jolicoeur, P., Gluck, M. A., & Kosslyn, S. M. (1984). Pictures and names: Making the connection. *Cognitive Psychology*, *16*, 243-275.

Joseph, R. M., & Tanaka, J. (2003). Holistic and part-based face recognition in children with autism. *Journal of Child Psychology and Psychiatry*, *44*, 529-542.

Kaufman, A. S., & Kaufman, N. L. (1994). *Kaufman Short Neuropsychological Assessment Procedure.* Circle Pines, MN: American Guidance Service, Inc.

Kéri, S. (2003). The cognitive neuroscience of category learning. *Brain Research Reviews, 43*, 85-109.

Kéri, S., Kálmán, J., Kelemen, O., Benedek, G., & Janka, Z. (2001). Are Alzheimer's disease patients able to learn visual prototypes? *Neuropsychologia*, *39*, 1218-1223.

Kéri, S, Kálmán, J, Rapcsak, S., Antal, A., Benedek, G., & Janka, Z. (1999). Classification learning in Alzheimer's disease. *Brain, 122*, 1063-1068.

Kéri, S., Kelemen, O., Benedek, G., & Janka, Z. (2001). Intact prototype learning in schizophrenia. *Schizophrenia Research*, *52*, 261-264.

Klin, A., & Jones, W. (2006). Attributing social and physical meaning to ambiguous visual displays in individuals with higher-functioning autism spectrum disorders. *Brain and Cognition*, *61*, 40-53.

Klin, A., Jones, W., Schultz, R., Volkmar, F., & Cohen, D. (2002). Visual fixation patterns during viewing of naturalistic social situations as predictors of social competence in individuals with autism. *Archives of General Psychiatry*, *59*, 809-816.

Klin, A., Sparrow, S. S., de Bildt, A., Cicchetti, D. V., Cohen, D. J., & Volkmar, F. R. (1999). A normed study of face recognition in autism and related disorders. *Journal of Autism and Developmental Disorders, 29*, 499-508.

Klinger, L. G., & Dawson, G. (1995). A fresh look at categorization abilities in persons with autism. In E. Schopler & G. Mesibov (Eds.), *Learning and Cognition in Autism* (pp. 119-136). New York: Plenum Press.

Klinger, L. G., & Dawson, G. (2001). Prototype formation in autism. *Development and Psychology*, 13, 111-124.

Klinger, L. G., Klinger, M. R., & Pohlig, R. L. (2006). Implicit learning impairments in autism spectrum disorders: Implications for treatment. In J.M. Perez, P. M. Gonzalez, M. L. Comi, & C. Nieto (Eds.), *New Developments in Autism: The Future is Today* (pp. 75-102). Kingsley Press: London.

Knowlton, B. J., & Squire, L. R. (1993). The learning of categories: Parallel brain systems for item memory and category knowledge. *Science, 262*, 1747-1749.

Lahaie, A., Mottron, L., Arguin, M., Berthiaume, C., Jemel, B., & Saumier, D. (2006). Face perception in high-functioning autistic adults: Evidence for superior processing of face parts, not for a configural face-processing deficit. *Neuropsychology, 20*, 30-41.

Lewis, P., & Strauss, M. S. (1986). Infant concept development. In G. Whitehurst (Ed.), *Annals of Child Development*. Connecticut: J. A. I. Press.

Lord, C., Rutter, M., Goode, S., Heemsbergen, J., Jordan, H., Mawhood, L., et al. (1989). Autism diagnostic observation schedule: A standardized observation of communicative and social behavior. *Journal of Autism and Developmental Disorders*, *19*, 185-212.

Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism Diagnostic Interview-Revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders*, *24*, 659-695.

Mazefsky, C. A., & Oswald, D. P. (2007). Emotion processing in Asperger's syndrome and high-functioning autism: The importance of diagnostic criteria and cue intensity. *Journal of Autism and Developmental Disorders*, *37*, 1086-1095.

Minshew, N. J., Goldstein, G., Muenz, L. R., & Payton, J. B. (1992). Neuropsychological functioning in non-mentally retarded autistic individuals. *Journal of Clinical and Experimental Neuropsychology*, *14*, 749-761.

Minshew, N. J., Meyer, J., & Goldstein, G. (2002). Abstract reasoning in autism: A dissociation between concept formation and concept identification. *Neuropsychology*, *16*, 327-224.

Molesworth, C. J., Bowler, D. M., & Hampton, J. A. (2005). The prototype effect in recognition memory: Intact in autism? *Journal of Child Psychology and Psychiatry*, *46*, 661-672.

Mottron, L., & Belleville, S. (1993). A study of perceptual analysis in a high-level autistic subject with exceptional graphic abilities. *Brain and Cognition, 23*, 279-309.

Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders, 36*, 27-43.

Murphy, G. L. (2002). *The big book of concepts.* Cambridge: MIT Press.

Norbury, C.F., Brock, J., Cragg, L., Einav, S., Griffiths, H., & Nelson, K. (2009). Eye-movement patterns are associated with communicative competence in autistic spectrum disorders. *Journal of Child Psychology and Psychiatry*, *50*, 834-842.

Nosofsky, R. M., & Kantner, J. (2006). Exemplar similarity, study list homogeneity, and short-term perceptual recognition. *Memory & Cognition, 34*, 112-124.

O'Toole, A.J., Deffenbacher, K.A., Valentine, K., McKee, K., Huff, D., & Abdi, H. (1998). The perception of face gender: The role of stimulus structure in recognition and classification. *Memory and Cognition, 26,* 146-160.

Ozonoff, S. (1997). Components of executive functioning in autism and other disorders. In J. Russell (Ed.), *Autism as an executive disorder* (pp. 179-211). New York: Oxford University Press.

Pelphrey, K.A., Sasson, N.J., Reznick, J.S., Paul, G., Goldman, B.D., Piven, J. (2002). Visual scanning of faces in autism. *Journal of Autism and Developmental Disorders, 26*, 146-160.

Plaisted, K., O'Riordan, M., & Baron-Cohen, S. (1998). Enhanced discrimination of novel, highly similar stimuli by adults with autism during a perceptual learning task. *Journal of Child Psychology and Psychiatry, 39*, 765-775.

Plaisted, K. C. (2000). Aspects of autism that theory of mind cannot explain. In Baron-Cohen, S., Tager-Flusberg, H. & Cohen, D. J. (Eds.), *Understanding Other Minds: Perspectives from Developmental Cognitive Neuroscience*. New York: Oxford University Press.

Posner, M. I., Goldsmith, R., & Welton, K. E. (1967). Perceived distance and the classification of distorted patterns. *Journal of Experimental Psychology*, *73*, 28-38.

Posner, M. I., & Keele, S. W. (1968). On the genesis of abstract ideas. *Journal of Experimental Psychology*, *77*, 353-363.

Quinn, P. C. (1987). The categorical representation of visual pattern information by young infants. *Cognition, 27*, 145-179.

Quinn, P. C., & Oates, J. M. (2004). Early category representations and concepts. In J. M. Oates & A. Grayson (Ed.), *Cognitive and language development in children, 2nd Edition* (pp. 21-60). Oxford, UK: Blackwell Publishers.

Ramsey, J. L., Langlois, J. H., & Marti, N. C. (2005). Infant categorization of faces: Ladies first. *Developmental Review, 25*, 212-246.

Reed, S. K. (1972). Pattern recognition and categorization. *Cognitive Psychology, 3*, 382-407.

Rhodes, G., Brennan, S., & Carey, S. (1987). Identification and ratings of caricatures: Implication for mental representations of faces. *Cognitive Psychology, 19,* 473-497.

Rubenstein, A. J., Kalakanis, L., & Langlois, J. H. (1999). Infant preferences for attractive faces: A cognitive explanation. *Developmental Psychology, 35*, 848-855.

Rump, K.M., Giovannelli, J.L., Minshew, N.J., & Strauss, M.S. (2009). The development of emotion recognition in individials with autism*. Child Development, 80,* 1434-1447.

Smith, J. D. (2002). Exemplar theory's predicted typicality gradient can be tested and disconfirmed. *Psychological Science, 13*, 437-442.

Smith, J. D., Redford, J. S., Gent, L. C., & Washburn, D. A. (2005). Visual search and the collapse of categorization. *Journal of Experimental Psychology-General, 134*, 443-460.

Solso, R. L., & McCarthy, J. E. (1981). Prototype formation of faces: A case of pseudo-memory. *British Journal of Psychology, 72*, 499-503.

Strauss, M. S. (1979). The abstraction of prototypical information by adults and 10-month old infants. *Journal of Experimental Psychology: Human Learning and Memory*, *50*, 618-632.

Strauss, M., Newell, L., & Best, C. (2003, April). *The development of face expertise: The perception and recognition of faces by infants, preschoolers and individuals with autism*. Paper presented at the Society for Research in Child Development Biennial Meeting, Tampa, FL.

Strauss, M. S., Newell, L. C., Best, C. A., Giovannelli, J., & Minshew, N. J. The development of facial gender discrimination in typically developing individuals and individuals with autism. Manuscript submitted for publication.

Tager-Flusberg, H. (1985). Basic level and superordinate level categorization in autistic, mentally retarded, and normal children. *Journal of Experimental Child Psychology*, *40*, 450-469.

Tanaka, J. W., & Taylor, M. (1991). Object categories and expertise: Is the basic level in the eye of the beholder? *Cognitive Psychology*, *23*, 457-482.

Ungerer, J. A., & Sigman, M. (1987). Categorization skills and receptive language development in autistic children. *Journal of Autism and Developmental Disorders*, *17*, 3-16.

Valentine, T. (1991). A unified account of the effects of distinctiveness, inversion, and race in face recognition. *The Quarterly Journal of Experimental Psychology, 43A*, 161-204.

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence*. San Antonio: The Psychological Corporation.

Weissman, M.M., Wickramaratne, P., Adams, P., Wolk, S., Verdeli, H., & Olfson, M. (2000). Brief screening for family psychiatric history: The family history screen. *Archives of General Psychiatry, 57*, 675-682.

Younger, B. (1985). The segregation of items into categories by ten-month-old infants. *Child Development*, *56*, 1574-1583.

Younger, B. (1990). Infant categorization: Memory for category-level and specific item information. *Journal of Experimental Child Psychology*, *50*, 131-155.

Younger, B., & Gotlieb, S. (1988). Development of categorization skills: Changes in the nature or structure of infant form categories. *Developmental Psychology*, 24, 611-619.

Zaki, S. R., Nosofsky, R. M. (2004). False prototype enhancement effects in dot pattern categorization. *Memory & Cognition, 32*, 390-398.

Zaki, S. R., & Nosofsky, R. M. (2007). A high-distortion enhancement in the prototype-learning paradigm: Dramatic effects of category learning during test. *Memory & Cognition*, *35*, 2088-2096.