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Visual Gaze Patterns during Implicit Learning in Persons with Autism Spectrum Disorder

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Abstract

It is theorized that some of the social impairments seen in Autism Spectrum Disorder (ASD) are due to differences in implicit learning. Individuals with ASD have been shown to have differences in implicit learning compared to individuals with typical development. It was hypothesized that one possible cause for implicit learning differences is an underlying attention dysfunction. The eye gaze of ten individuals with ASD and ten individuals with typical development was tracked while they performed an implicit prototype learning task using cartoon animals. While moderately-sized differences in prototype learning were found, large differences were found in the eye gaze patterns of individuals with ASD compared to individuals with typical development, including number of fixations, attention to critical regions of interest, as well as attention to the faces of the stimuli. Additionally, it was found that some parts of visual gaze were strongly related to implicit learning task performance for both groups of individuals. Thus, results support the idea that attention differences may be related to implicit learning differences in ASD. Implications for the implicit learning theory of ASD and face processing in ASD are discussed.

Keywords: Attention; Autism, Gaze; Implicit learning; Visual

Introduction

Autism Spectrum Disorder (ASD) is a pervasive developmental disorder usually diagnosed in childhood and characterized by impairments in the development of social communication and interaction skills, as well as a restricted repertoire of behaviors and interests and behaviors, according to the Diagnostic and Statistical Manual of Mental Disorders [1]. While the term was previously used to include diagnoses of autism, Asperger's syndrome, and Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS), it exists now as a singular diagnosis including the two aforementioned primary characteristics, with specification of other intellectual or language impairment, neurodevelopmental disorder, behavioral disorder, mental disorder, or catatonia. A great deal of research has focused on the cognitive differences in individuals with ASD, and there are a number of models of the underlying cognitive differences in ASD. One idea with a good deal of support is that the social processing impairments associated with the disorder are secondary effects of primary differences in one or more cognitive skills. Two essential aspects of cognitive processing that have been implicated in ASD are implicit learning and attention. Differences in both implicit category learning and attention in ASD are well documented [2-4]. The goal of the current study was to look at the relationship between implicit learning and attention in persons with ASD to help understand how these cognitive processes interact in ASD and to see if the relationship differs from typically developing individuals.

Implicit Learning and Prototype Learning In ASD

Implicit learning is a type of automatic cognitive skill that is present in the first year of life. Reber (1993) [5] defined implicit learning as the learning of knowledge without the conscious effort to learn, and without the conscious knowledge of what was learned. Implicit learning is independent of differences in intelligence [6,7] and chronological age [8,9], and is thought to underlie the development of social intuition [10] and language [11]. This is in contrast to explicit learning, in which persons have conscious knowledge of what was learned. Explicit learning is the use of effortful, strategic mental processes to learn information, and is dependent on intelligence [12,7] and chronological age [12].

One example of implicit learning is prototype learning, which occurs when information from a set of stimuli is automatically extracted to help understand the mental category to which it belongs. Individual features of stimuli are extracted, and then compared to features of the categories previously stored, much like pattern recognition. Once a stimulus is added to a category, the category is somewhat changed, in that it has taken on the properties of the added stimulus, typically occurring without effort nor awareness. A common approach to measuring category formation is a prototype formation task. Posner and Keele (1970) [13] proposed that when natural categories are somewhat ambiguous, the person learns by extracting the best example of the category, the prototype. The prototype is theorized to be created by making a mental average of the encountered category members. In experiments, following familiarization of category members that vary on different features, participants can discriminate between novel members of the category and the prototype (the mathematical average of all features) with little difficulty, though both of them are novel to the participant. Participants typically categorize the prototype stimuli as a familiar member. Category learning, as well as implicit learning, is thought to be an important part of social development. The ability to automatically extract information from a situation and learn categories and rules of social interaction is an integral aspect of social intuition [10].

Several studies have compared the categorization abilities of individuals with ASD to individuals with typical development. Though some findings differ, there is evidence that this process seems to be different in those with ASD. Prototype learning was shown to be different in individuals with ASD in a study by Klinger and Dawson (2001) [2], which used a prototype learning task using cartoon animals. Participants were individuals with ASD, Down syndrome, and typical development, aged 5 to 21 years, with a receptive language ages of between 4 and 12 years. During an exposure phase, the participants saw eight variations of an animal category, which varied on four features (e.g., length of leg, width of neck); however, the participants did not see the prototype animal. During the test phase, the participants were shown two animals and asked to choose which animal was a member of the target category. The stimuli in the test phase consisted of a novel example of the target animal paired with either the prototype animal or a target animal that was previously seen. Children with typical development chose the prototype 79% of the time, suggesting that they had successfully learned the prototype.

Individuals with ASD did not choose the prototype significantly greater than chance (54%), suggesting that they had not learned the prototype. However, on a rule-based category learning task in which category membership was determined by a simple rule, the performance of individuals with ASD was similar to typically developing individuals. This suggests that explicit learning is not impaired in individuals with ASD.

Molesworth, Bowler, and Hampton (2005) [14] showed somewhat conflicting results in a study of recognition memory and prototype learning in high functioning individuals with ASD and typical development. The authors used a task similar to Klinger and Dawson (2001) [2] but during the test phase, had the participants decide if they recalled seeing the animal in the previous exposure phase. Persons with ASD and typical development showed similar prototype effects on this task. These results may differ from Klinger and Dawson (2001) [2] because of differences in participant groups and/or differences in methodology. The participants in Klinger and Dawson (2001) [2] were younger in chronological and mental age and had more intellectual disability than the participants in Molesworth et al.'s study The older participants in the study by Molesworth et al. were possibly better at the task than the younger participants in the study by Klinger and Dawson. The Molesworth et al. study also had the participants decide if they remembered the animal, as opposed to having participants chose which animal was the target animal as in Klinger and Dawson's study.

Klinger, Klinger, and Pohlig (2006) [15] have suggested that mental age differences between the participant groups may be the cause of the contrasting findings in [2,14]. The study by Klinger, Klinger & Pohlig (2006) [15] involved two implicit learning tasks. One of the tasks was a replication of the [2] prototype learning experiment. The other task was an artificial grammar learning task, in which there were sequences of shapes that had underlying complex rules as to how the sequences were made, though these rules were not explained. After familiarization, participants had to indicate which sequences followed the rules of sequences seen during familiarization. On both the prototype task and the artificial grammar task, individuals with typical development performed significantly better than individuals with ASD, replicating [2]. Also, implicit learning scores were correlated significantly with ASD symptom scores (measures of social skills problems, language problems, and repetitive behaviors). Most importantly, implicit learning performance was related to measures of explicit reasoning, indicating that individuals with ASD may use explicit reasoning processes to compensate for implicit learning differences. Specifically, children with ASD who had mental ages less than 10.5 years old performed poorly on both tasks of implicit learning, but children with ASD who had mental ages greater than 10.5 performed at a level equivalent to children with typical development. Thus, the reason why [2] showed differences but [14] did not may be due to the mental ages of the participants used. Klinger, Klinger, & Pohlig (2006) [15] theorized that there are several possible mechanisms that could account for the difference in implicit learning in ASD and the correlation between implicit and explicit learning in individuals with ASD. The first is that there is some basic difference in implicit learning in ASD, and individuals use explicit learning to compensate.

The second is that individuals with ASD simply prefer to use explicit learning instead of explicit learning. Previous research has shown that adopting an explicit learning strategy can, under some circumstances, decrease implicit learning task performance [16,17]. Therefore, if individuals with ASD prefer to use explicit processes to perform implicit learning tasks, this could lead to both their decreased performance and the strong relationship between implicit and explicit learning in this group. The third is that attentional problems make it difficult for individuals with ASD to attend to all parts of a stimuli and relationships across stimuli, causing them to show impaired implicit learning. However, they may compensate for these attentional differences by relying on more explicit attention processes. This thesis tests the relationship between attentional processes and implicit learning.

Visual Attention in ASD

Visual attention can be thought of as the area of the environment that is captured by active visual processing. Visual attention can take in a large area of the environment, or it can also focus on or attend to certain smaller areas. When visual attention is focused on certain parts of the environment and stimuli, especially when unexpected, it is often called orienting. Visual orienting typically falls into two categories according to [18], based on the stimuli presented. The first category of visual orienting is toward novel stimuli. This is usually an involuntary shift of attention, involving a change that occurs in an otherwise constant visual scene. After a number of instances of the novel stimulus, there is a gradual reduction of this orienting, known as habituation, as the initial change in the visual scene becomes part of the constant visual scene. The second category of visual orienting is toward important information. Important information is information that it is significant to the individual. An example of important information in the visual scene could be the nametag of a person at a conference. Posner, Walker, Friedrich, and Rafal (1984) [19] proposed that visual attention happens in three steps: disengagement, shift, and engagement. Disengagement refers to breaking the visual attention away from the current focus. The shift is simply the movement from the previous stimulus to the next stimulus. Engagement is the focus of the visual attention on the new stimulus.

There is behavioral and neurological evidence for impaired attentional abilities in individuals with ASD. A difference in the ability of individuals with ASD to shift attention has been shown by Courchesne, Townsend, and Akshoomoff (1994) [20]. Courchesne et al. compared children and adolescents with ASD to individuals with cerebellar lesions and to individuals with typical development on a task involving shifts of attention from visual stimuli to auditory stimuli and back again. The individuals with ASD and cerebral lesions were poorer at the attention shifting tasks than individuals with typical development. This could be a difference in either the shifting or disengaging step of the visual process. The authors concluded that the individuals with ASD had differences in shifting attention rapidly to new stimuli, which could cause the social and cognitive differences in the disorder. Others have shown similar differences in shifting and disengaging attention in persons with ASD [21].

Research by Mann and Walker (2003) [22] studied the over-focused attention that is often characteristic of individuals with ASD. Using a design with different sized crosshairs, the study showed that individuals with ASD take significantly longer to attend to stimuli as they were going from small to large. This led to their conclusion that the specific process of making the visual attention field larger is impaired in ASD. This would account for why individuals with ASD only obtain parts of information, and would be most congruent with an impaired level of disengagement in ASD. Research by Landry and Bryson (2004) [21] also showed a difference in the level of disengagement of visual attention in ASD. When a central stimulus was presented and removed before a second stimulus was presented, persons with ASD shifted attention in comparable speeds to typically developing individuals. However, when the first fixation stimulus remained visible for the presentation and duration of the second target stimulus, persons with ASD were significantly slower at shifting their attention to the target, and in some trials, never shifted attention from the first fixation stimulus.

A study by van der Geest, Kemner, Camfferman, Verbaten, and van Englund (2001) [23] examined the level of engagement of visual attention in individuals with ASD, using a gap-and-overlap paradigm. In a gap condition, the fixation point is removed, and in an overlap condition, the fixation point remains on the screen when a target stimulus is presented. Saccadic reaction times (measurements of the reflexive movements of the eyes) are generally shorter in the gap condition, called the gap effect. However, individuals with ASD showed a small gap effect, suggesting that individuals with ASD are different in their level of engagement, as opposed to other theories that shifting or disengagement is the different process. Although research consistently reveals problems with attention and orienting in ASD, the specific difference has shown to be variable from one study to another. Neurobiological evidence for a primary difference in attention in ASD includes Functional Magnetic Resonance Images (fMRI) and Magnetic Resonance Images (MRI) that reveal abnormalities in the neocerebellum of the brain of individuals with ASD and abnormally increased sulcal width in the parietal cortex of almost half of individuals with ASD [4,24]. These areas in the brain are proposed to be responsible for important visual attentional processes.

One of the most widely accepted theories for integrating these differences in attention in ASD is the Weak Central Coherence Theory. Frith (1989) [25] proposed that an attentional difference was responsible for an inability or failure to integrate component features of a situation into a coherent whole. Happe (1997) [26] found evidence for weak central coherence by showing that individuals with ASD did not look at the context of a sentence in choosing a correct pronunciation of a word a homophone sentence (e.g., reading "tear" in the phrase "tear in her dress."). Individuals with ASD have also been shown to perform better on tasks of block designs and embedded figures, providing more evidence that individuals with ASD appear to be paying attention to the parts instead of the whole [27,28]. The weak central coherence theory would attribute slower reaction times of individuals with ASD seen in studies such as Mann and Walker (2003) [22] to more focused attention to the parts of the cues and shapes than their typical counterparts. The weak central coherence theory also accounts for some underlying neural component, not unlike the component for attention shown in the Townsend and Courchesne (1994) [4] study. Additionally, this theory accounts for the visual-perceptual strengths seen in some individuals with ASD.

The Present Study

To further test why impaired implicit learning is impaired in ASD, the present study examined the relationship between visual attention and implicit learning in persons with ASD, and to test whether attentional differences are related to implicit learning in ASD. The present study used a prototype learning task and measured attention by using an eye-tracking device during task performance. The present study examined how attention is directed at features of categories, how shifts of attention occur in ASD, and whether these shifts are different from those occurring in the typical population. Finally, the present study tested whether differences in the attentional processes between typically developing individuals and individuals with ASD are related to differences in prototype learning in ASD.

The goal of the present study was to measure aspects of attention and their relationship to category learning in individuals with ASD. The specific hypotheses were: 1) Individuals with ASD would display a smaller false recognition prototype effect compared to typically developing individuals. However, this study used older participants (ages 12 – 22) than participants used in [2]. In the study by Klinger, Klinger, and Pohlig (2006) [15], participants in this mental age range performed well on the prototype task. Therefore, individuals with ASD may show similar or only slightly poorer performance compared to individuals with typical development on the prototype task (but younger individuals proved difficult to capture using the selected eye-tracking equipment).

2) Individuals with ASD would display a significantly reduced number of fixation points during exposure and test trials than typically developing individuals. 3) Typically developing individuals would attend to predefined areas of interest (AOIs), the critical varying features of the stimulus animals, for more fixations and more time during the exposure and test phases than individuals with ASD. 4) The size of the prototype false recognition effect in individuals with ASD would be significantly correlated with the mean number of fixations at exposure and test trials and with the amount of time attending to the regions of interest at exposure and test trials.

Materials and Methods

Design

The study used a 2 X 3 design to test the hypotheses. There were two diagnostic groups (typical development, autism) and three test stimulus types (old, new, and prototype animals), varying within participants. The design had two types of dependent variables, behavioral responses to the task and eye fixation data.

Participants

Ten individuals with ASD (9 male, mean age = 17.1 years) and 10 individuals with typical development (9 male, mean age = 17.4 years) participated in the study in exchange for either course credit or a $10 gift card. All participants with ASD had been previously diagnosed in the University of Alabama Autism Spectrum Disorders Research Clinic using the Autism Diagnostic Interview – Revised (ADI-R; [29]. Participants were selected and matched on the basis of raw verbal performance on the Kaufman Brief Intelligence Test 2 (K-BIT2; [30]. Participant characteristics can be seen in (Table 1). As can be seen, the two groups were very similar and did not significantly differ on chronological age, verbal performance on the K-BIT2, matrices performance on the K-BIT2, or overall IQ. There were also 7 individuals (4 with typical development, 3 with ASD) whose visual gaze could not be accurately tracked for the current study, due to loss of data during the procedure or failure to calibrate.

Participant Characteristics	TD	ASD
N	10	10
Age (Years-Months)	17-4	17-1
K-BIT		
IQ	109	104
Verbal Raw	86	82
Matrices Raw	38	38
ADI-R Domain Scores		
Social	N/A	17.0
Verbal Communication	N/A	10.6
Restrictive/Repetitive Behavior	N/A	5.3
Sex (M: F)	9:01	9:01

Table 1: All tests of difference were nonsignificant.

Measures

Kaufman Brief Intelligence Test 2 (K-BIT2; [30]. The K-BIT2 is a standardized measure of intellectual ability containing three subtests, with one measure of nonverbal intelligence (Matrices) and two measures of verbal intelligence (Verbal Knowledge and Riddles). The K-BIT2 takes about 30 minutes to administer. The K-BIT2 has appropriate norms for ages four to 90 with IQ scores ranging from 40 to 160. Test-retest reliability for the K-BIT2 IQ Composite is excellent, with a mean of .90. K-BIT2 IQ Composite scores correlate highly, r = .77, with the Weschler Intelligence Scale for Children-IV (WISC-IV). The individuals with ASD and typically developing individuals were matched in verbal mental age (raw score on combined Verbal Knowledge and Riddles).

Apparatus and Stimuli

The experiment was run on an IBM-compatible computer with a 17 inch VGA color monitor used for presenting stimuli and gathering data. Participants sat approximately 24 inches from the monitor. Participants used a chin rest mounted to the table which put their line of sight even with the center of the monitor. Reponses were recorded through the keys "A" and "6" on the standard keyboard. An Applied Science Laboratories (ALS) Model 504 eye-tracking video camera with infrared illumination was used to capture and monitor the participant's gaze. The eye-tracker was placed approximately 20-22 inches away from participants at approximately 25 degrees below the line of sight for participants. The ALS Eye-Tracker Interface software was run on a second IBM-compatible computer that took information from the video camera and plotted it on an x, y coordinate plane overlaid with the monitor that the participants viewed during the experiment. There were also two seven inch monitors seen by the experimenter to aid in capturing the eye with the camera and to monitor the output on the computer monitor seen by the participants. Stimuli were 48 black and white pictures of imaginary animals (12 pictures per animal; four animal categories) created using Adobe Illustrator, based on the methodology and animals of [31,2].

There were four animal categories, each similar in complexity, and given simple three letter names such as DAK or PIP. Each animal category had four features that varied in size across the 12 instances of that animal. For example, the DAK varied on width of whiskers, width of neck, length of arms, and length of ears (Figure 1). The features varied mathematically with the smallest variation being assigned the value of one and the largest variation being assigned the value of five. For instance, the neck feature of the DAK was .25 inches at value one, increasing by .25 inches at each value, making the value five dimension 1.25 inches in width. Familiarization stimuli had feature values of one, two, four, and five. There was a different set of values for each example of an animal, such as 1515, 2244, or 5511. The value of three for each feature (3333) was reserved for the prototype of the animal, the mathematical average of the features of the familiarization animals. There was also a small asterisk used as a fixation point in the task. The animals appeared in black and white with a light blue background. There was also a calibration grid used with the numbers one through nine presented in a 3 x 3 grid across the screen to help calibrate the eye-tracker.

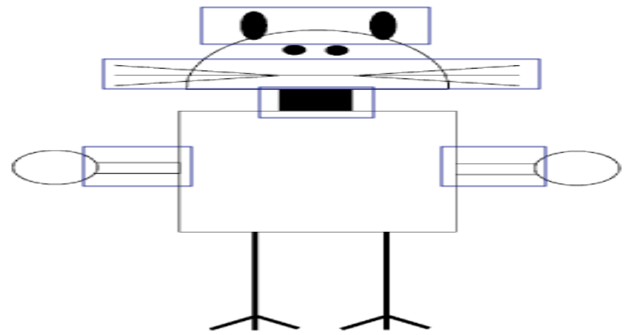

Figure 1: AOIs for the DAK.

Procedure

Participants were scheduled for one and a half hour time slots. Participants entered the lab and were given an informed consent form with a brief overview of the experiment, or a parent was given the consent form in cases where the participant was younger than age 18. Participants under 18 were also asked to read a brief description and provide verbal assent. Upon completion of the consent procedures, participants were given more specific instructions. Participants were given a schedule of what would happen, and in what order, during the experiment.

Participants were told that first they would play a computer game, where they would look at a screen with the numbers on it and keep their chin on a chin rest keeping as still as possible. Participants were then told that they would see four series of animals. They were told to look at the animals while keeping their head as still as possible. Participants were instructed that they would see 8 animals and they should look at each animal until it disappears, as they would have to answer questions about them later. Participants were told after each set of eight exposure animals that there were nine animals that they would have to answer a question about. They were asked to say if the animal was seen in the previous set of animals or not. If the animal was previously seen, participants were instructed to press "6" on the keyboard; if the animal was not seen previously, they were instructed to press "A" on the keyboard. A fixation point preceded each animal, and participants were instructed to direct their attention to it each time it appeared. Participants had the opportunity to ask any questions, the questions were answered, and participants began the task.

Prototype task

For this task, instructions initially appeared, followed by a prompt to begin the experiment. Participants completed four sets of animals. The procedure for each of the four sets of animals was identical. The first part of each animal set was a familiarization block (exposure) of eight stimuli. At the beginning of each trial, a fixation point (an asterisk) appeared against a light blue background for 58ms. The stimulus then appeared on the screen for 6 seconds while participants were told to keep looking at the animal, and the name of the animal was said ("This is a PEV."). Following the animal stimulus, a 2-second blank stimulus was presented. This was repeated for a total of eight randomly ordered familiarization trials. Following this, the block of test trials began. Participants completed nine test trials. Test trials included three types of trials: old stimuli that were seen before, new stimuli that were not seen before, and the prototype for the animal set. Test trial stimuli were randomly ordered, with no one type of stimulus appearing consecutively. Participants were instructed to press "A" if they had not seen the stimulus in the familiarization block or "6" if they had seen it during familiarization. The test stimuli remained on the screen until the participants responded. There were three trials of each type of test animal presented in a test block. Participants completed trials for four sets of animals. The order of animal sets was counterbalanced. Following completion of the prototype task, participants completed the K-BIT2.

Results

Prototype Task Performance

All results represent means across all 4 animal categories unless otherwise specified. Recognition responses (i.e., participants says they have seen the animal before) were recorded for each type of stimulus presented during test with a mean percent calculated for old, new, and prototype stimuli across the 4 animal categories. The mean percent of recognition responses are presented in (Table 2). As can be seen, for both diagnostic groups, recognition responses occurred more frequently to the prototype stimuli than the old or new stimuli. A 2 X 3 ANOVA was performed using the response data from the test phase, with diagnosis as a between subjects variable and stimulus type (old, new, and prototype) as a within subjects variable. A significant effect of stimulus type was observed, $F [2, 36] = 42.00$, $p < .001$. Post-hoc Tukey's LSD analyses revealed that across all participants, recognition responses were higher to the prototype stimuli than to either the old or new stimuli ($p < .01$ for both tests). Additionally, a main effect for diagnosis was observed, $F [1, 18] = 5.95$, $p = .03$, indicating a response bias in which participants with ASD responded yes more frequently than persons with typical development to all stimuli. However, no interaction between diagnosis of participants and stimulus type was found, $F [2, 36] = 1.42$, $p = .26$. A planned follow-up analysis showed that there were significantly fewer recognition responses to new stimuli than to prototype stimuli for individuals with typical development, $t (9) = 10.76$, $p < .01$, Cohen's $d = 3.47$, and individuals with ASD, $t (9) = 3.92$, $p < .01$, $d = 1.82$. Planned contrasts for recognition responses to prototype and new stimuli (i.e., the prototype effect) were also examined. The mean prototype effect (calculated by subtracting the mean performance on novel stimuli from the mean performance on prototype stimuli) for the persons with typical development was .47; for persons with ASD, the mean prototype effect was .33. While there was only a marginal difference between the groups on the size of the prototype effect, $F [1, 18] = 2.30$, $p = .15$, the effect size for this difference was moderate to large ($d = .68$).

Stimulus Type	TD	ASD
Old	0.64	0.73
Prototype	0.81	0.87
New	0.34	0.54
Prototype Effect (Prototype – New)	0.47	0.33

Table 2: Recognition Responses to Old, New, and Prototype Stimuli.

Eye Fixations

Eye fixation data were recorded during the prototype task using ASL eye-tracker software, and were processed and analyzed using a combination of ASL Eye Analysis and Fixplot software and SPSS. The software defaults for criteria of fixations were used (maximum change in gaze point = 1 degree visual angle, minimum time = 100 ms), and the total number of fixations recorded during both exposure and test phases were divided by the number of trials in each phase to get an average number of fixations per trial for each participant. (Table 3) Combining exposure and test phases, the number of fixations for persons with typical development was 10.3 per trial, while the number of fixations for persons with ASD was 8.9 per trial. A t-test revealed this to be a large, significant difference, $t (18) = 2.15$, $p = .05$, $d = .96$. The number of fixations at exposure and test were then examined for differences between the groups. At exposure, persons with typical development had 12.7 fixations per trial, while persons with ASD had 11 fixations per trial. A test of significance revealed this to be a large but nonsignificant difference, $t (18) = 1.66$, $p = .11$, $d = .78$. At test, persons with typical development had 8.2 fixations per trial, while persons with ASD had 7 fixations per trial. A t-test showed this to be a large and marginally significant difference, $t (18) = 1.91$, $p = .07$, $d = .90$.

	TD	ASD
Number of Fixations		
Exposure Trials	12.7	11
Test Trials	8.2	7.0*
Combined (average)	10.3	8.9**
Duration of Gaze per Trial		
Exposure Trials	6.1 sec	6.1 sec
Test Trials	3.8 sec	3.5 sec
Combined (average)	4.9 sec	4.7 sec*
Duration of Fixations		
Exposure Trials	.49 sec	.59 sec
Test Trials	.47 sec	.52 sec
Combined (average)	.48 sec	.55 sec*
* p ≤ .10 ** p ≤ .05 *** p ≤ .01		

Table 3: Eye Gaze for Persons with Typical Development and ASD.

Duration of participant gaze was also examined; the mean durations of fixations can also be found in (Table 3). A marginal difference in the duration of each individual fixation, t (18) = -1.92, p = .07, d = -.91. The difference in the duration of gaze by trial was also examined, which is the total looking time per trial (subtracting out fixation loss and shifting time) and varies with each participant. This was not significantly different between the groups, t (18) = 1.30, p = .21, d = .61.

Areas of Interest

Fixations and durations of fixations were also examined within predefined areas of interest (AOIs). As previously stated, these AOIs were the features of each animal category that varied across instances of that animal category (e.g., the DAK varied on width of whiskers, width of neck, length of arms, and length of ears). The areas were specified graphically using ASL Fixplot. Then numbers and durations of fixations were calculated for each AOI, for each stimulus of each animal category. The means across animal categories are presented in (Table 4). At exposure, persons with typical development had 7.0 fixations per trial within AOIs, while persons with ASD had 5.7 fixations per trial within the same areas. This was a large, statistically significant difference, t (18) = 2.35, p = .03, d = 1.05. At test, persons with typical

development had 4.4 fixations per trial within AOIs, while persons with ASD had 3.5 fixations per trial within the areas, again a large, significant difference, t (18) = 2.63, p = .02, d = 1.18. The number of fixations within the AOIs combined across exposure and test was found to be large and significantly greater for persons with typical development than persons with ASD, t (18) = 2.75, p = .01, d = 1.23.

	TD	ASD
Fixations within AOIs		
Exposure Trials	7	5.7**
Test Trials	4.4	3.5**
Combined (average)	5.6	4.7***
Duration within AOIs		
Exposure Trials	2.9 sec	2.9 sec
Test Trials	1.9 sec	1.6 sec
Combined (average)	2.2 sec	2.1 sec
Number of AOIs Attended		
Exposure Trials	3.6	3.3
Test Trials	3.3	3
Combined (average)	3.5	3.2*
* p ≤ .10 ** p ≤ .05 *** p ≤ .01		

Table 4: Gaze Patterns within AOIs.

Duration of fixations within AOIs were examined by calculating the total duration for fixations that were in the AOIs and dividing by the number of trials. Durations within areas at exposure and test can be seen in (Table 4). No significant difference in the amount of time spent in AOIs at exposure was found, t (18) = -.20, p = .84, d = -.09, at test, t (18) = 1.45, p = .16, d = .68, or when exposure and test were combined, t (18) = .56, p = .58, d = .26. However, there was a difference in duration of fixations within AOIs for two specific animals at exposure trials. For the GEB, the persons with ASD were fixated for longer durations within AOIs per trial (3.9 sec) than the persons with typical development (3.1 sec), t (18) = -2.75, p = .01, d = -1.23). However, this may be partially due to the fact that the torso was a main AOI that lay directly over the fixation point and persons with ASD attend to this feature for especially long times. It might be expected that persons with ASD had trouble disengaging their attention from this area, in part, due to the overlay with the fixation point. But for the ZOG, the persons with typical development were fixated for longer durations within AOIs per trial (3.8 sec) than persons with ASD (3 sec), t (18) = 2.29, p = .03, d = 1.03. In the ZOG animal category, the fixation point did not occupy the same position as a critical varying feature of the category, suggesting that, indeed, there may be difficult for persons with ASD to disengage from the fixation point. Other differences for individual animal categories are discussed in greater depth later.

The number of AOIs that each participant attended to (the number of areas participants recorded a fixation within) at exposure and test phases was then calculated. There were a total of four features for each category, so the maximum score for each participant was four. Moderate sized, nonsignificant differences were found between the groups on the number of areas attended at exposure (typical = 3.6, ASD = 3.3), t (18) = 1.15, p = .17, d = .54, and at test (typical = 3.3, ASD = 3.0), t (18) = 1.53, p = .14, d = .72. Large, marginal differences were observed for the combined exposure and test trials (typical = 3.5, ASD = 3.2), t (18) = 1.75, p = .10, d = .82.

Relating the Prototype Effect to Eye Tracking

Another research question was whether the number of fixations and the duration of fixations of participants were related to the prototype effect; across the two groups, the size of the prototype effect was examined for a correlational relation with the mean number of fixations, the mean number of fixations within AOIs, the mean number of AOIs attended, the mean duration of fixations, and the mean duration of fixations within AOIs. The number of fixations, duration of fixations, and duration of fixations within AOIs were not significantly related to the prototype effect (r = .34, r = .20, and r = .03, respectively). However, a strong, significant relation between the mean number of AOIs attended during test trials and the prototype effect was found, r [18] = .67, p = .001 (Figure 2). This relationship did not significantly differ between participants with typical development and participants with ASD, F [1, 16] = .69, p = .42. There was also a strong significant relation between the number of fixations within AOIs during exposure trials and the prototype effect, r [18] = .47, p = .04 (Figure 3). Again, this relationship between did not significantly differ between participants with typical development and participants with ASD, F [1, 16] = .002, p = .96.

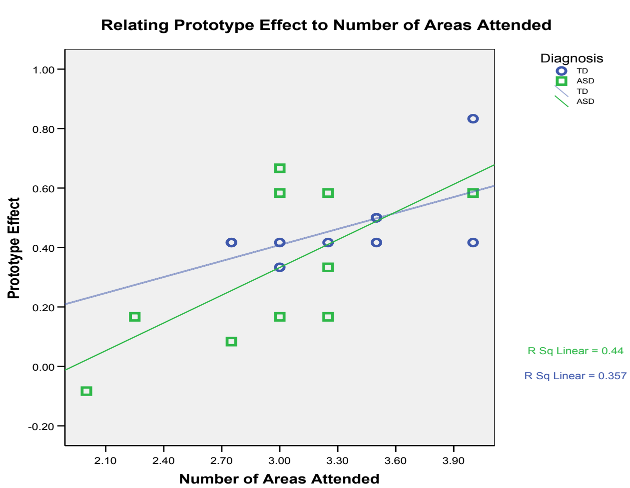

Figure 2: Relation between the Number of AOIs Attended during Test Trials and the Prototype Effect.

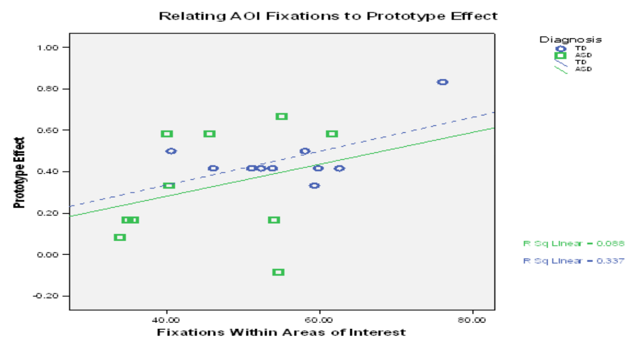

Figure 3: Relation between the Number of Fixations within AOIs during Exposure Trials and the Prototype Effect.

Additional Areas of Interest

Significant differences in the number of fixations in the predefined AOIs were found, but no significant differences in duration of fixations within those areas were found (though some duration effects were marginally significant). For both fixations and durations, data for each individual feature of each animal category were analyzed, and many areas were found in which persons with ASD had significantly fewer fixations and shorter durations than persons with typical development. Furthermore, a separate pattern emerged, where there were greater differences between the groups in fixations and durations in certain AOIs. More specifically, fixations within AOIs on and around the "head" of the cartoon animal were especially consistent; therefore, data were also analyzed with the head of the cartoon animals as an AOI. On the basis of research on face processing in ASD, it was decided that two additional AOI would also be defined for analyses: the eyes and mouth. Previous research on face processing has shown that persons with ASD have a tendency to attend to the eyes of human faces significantly less than persons with typical development [32]. Avoidance eye contact is also one of the hallmark signs of social interaction in ASD, and additional research has suggested that persons with ASD may attend to the mouth region more than persons with typical development [33,32].

The mean number and duration of fixations within the areas of the head, eyes, and mouth per trial were calculated, which can be seen in (Table 5). Combining across exposure and test trials, it was found that persons with typical development had a very large, significantly greater number of fixations in the head AOI compared to individuals with ASD, t (18) = 4.14, p < .01, d = 1.95. However, the duration of time within the head area did not significantly differ between the groups though they were moderate to large in size, t (18) = 1.53, p = .14, d = .72. In the eyes AOI, persons with ASD had significantly fewer fixations, t (18) = 3.15, p = .01, d = 1.50, and shorter durations, t (18) = 2.10, p = .05, d = .99, than persons with typical development, statistically large group differences. Within the mouth region, it was also found that persons with ASD had significantly fewer fixations than persons with typical development, t (18) = 2.49 p = .02, d = 1.17, but were not different on duration, t (18) = .36, p = .72.

	TD	ASD
Number of Fixations		
Head	3.3	2.0***
Eyes	0.6	0.2***
Mouth	0.8	0.5**
Duration of Fixations		
Head	1.4 sec	1.1 sec
Eyes	0.3 sec	0.2 sec**
Mouth	0.4 sec	0.3 sec
* p ≤ .10 ** p ≤ .05 *** p ≤ .01		

Table 5: Gaze Patterns to Head, Eyes, and Mouth Regions Across Exposure and Test Trials.

Discussion

Marginal differences, with moderate to large effect sizes, were shown between individuals with typical development and individuals with ASD on the prototype effect, suggesting that individuals with typical development showed a somewhat greater prototype effect than individuals with ASD. Analyses found that participants with typical development had overall more fixations than participants with ASD, although the mean duration of the fixations were similar between groups, with the a large effect size for the number of fixations. Persons with ASD also had significantly fewer fixations within areas representing the varying features of the animal categories than persons with typical development, a large effect. However, significant differences in the duration of fixations within these areas was not observed. A marginally significant difference in the number of AOIs attended was found, with participants with typical development attending to more critical features.

Additionally, a strong, significant relation between the number of AOIs attended and the size of the prototype effect was shown across both groups. It was also found that persons with typical development had a significantly greater number of fixations within the head, eyes, and mouth regions. While only marginal differences were shown between individuals with ASD and individuals with typical development in the overall prototype effect, it also showed an interesting pattern. As hypothesized, there was expected to be some difference, but that it might not be significant due to the older, high-functioning sample selected. While there was not a significant difference, there was a trend in the data, where individuals with typical development had a mean prototype effect of .47, and the individuals with ASD had a mean prototype effect of .33, showing a moderate to large effect size. This effect size is very similar to the effect size of diagnosis on prototype learning observed in [2,15] using similar prototype tasks, d = .68 and d = .75 respectively. While not a significant difference, this study echoes the finding of differences between persons with ASD and persons with typical development in prototype learning.

Molesworth, Bowler, and Hampton (2005) [15] suggested that previous findings of differences in prototype learning in ASD may have been to be due to instructional biases, where the categorization instructions of the previous studies were difficult for individuals with ASD to comprehend. This study used memory instructions instead of the categorization instructions, as well as single exposure and test presentation instead of the two-alternative forced-choice procedure used by [2,34]. Again, while not significant, the present study replicated the pattern of findings of previous prototype studies using an older, high-functioning group. This suggests that the impaired prototype effects previously observed may not be due to differences in understanding categorical instructions, but instead represent genuine differences in prototype learning in persons with ASD.

As hypothesized, it was expected that there would be significantly fewer fixations in the group with ASD compared to the individuals with typical development. This hypothesis was strongly supported, with persons with typical development having a statistically large difference in the number of fixations, d = .96. This supports theories of attentional differences in ASD, and is congruent with a theory of a disengagement difference in persons with ASD [22,21]. Which suggests that persons with ASD have trouble disengaging their attention from stimuli. Because the duration of each exposure time was similar, the duration of each individual fixation for individuals with ASD should be longer simply by having fewer fixations within the same amount of time as persons with typical development. However, the difference between durations of fixations at exposure was not significantly different, presumably because of higher variability in this score. At test trials, the total duration of each trial was dependent on when participants ended the trial by entering a response. However, the duration of fixations was again not significantly different by group. To put this together, the persons with ASD shifted their attention less often, but dwelled on objects of their attention for approximately the same amount of time as persons with typical development. It is possible that persons with ASD spent more time shifting attention, rather than focusing on particular features. However, there was no way to record shifting within the present study. This may suggest a difference in shifting of attention in persons with ASD.

To understand the differences between the groups more clearly, the specific areas of varying features of each animal category were examined. It was hypothesized that these features would be the critical parts of the stimuli to attend to, as they changed on every stimulus. To be able to learn the most about the category, these features would need to be seen and processed.

As hypothesized, it was found that persons with typical development looked at these features more often than persons with ASD. However, the duration of time within the AOIs showed no difference, providing evidence that the groups looked at the areas for approximately the same amount of time. Again, this fits with a disengagement theory, in that persons with ASD may remain locked on certain features and fail to disengage from the feature. However, the disengagement theory would also predict that the persons with ASD would have longer duration of fixations, which was not the case. This finding also sheds light on the previously discussed possible causes of implicit learning differences in persons with ASD; persons with ASD fixated less often on areas that contained critical features, and this may cause them to show decreased implicit learning. This would also support the idea that the critical features that vary across categories (in general) must be attended to and processed to form a prototype. Results were also examined regarding face processing in persons with ASD.

It was found that persons with typical development had more fixations than persons with ASD within the head, eyes, and mouth regions of the animals; this is interesting because only once was the head and mouth a critical changing feature, and the eyes were never a critical feature. However, the persons with typical development attended to these regions more than persons with ASD. These results relate to the facial processing differences in ASD, as although the stimuli used in the current study were cartoon animals, they did have somewhat anthropomorphic faces.

Pelphrey et al. (2002) [32] found that persons with ASD had significantly fewer fixations than persons with typical development on what was deemed the critical regions of the face, the eyes, nose, and mouth. This was congruent with most research on face processing in persons with ASD with one exception: the mouth region. Some previous studies have suggested that the mouth region may be attended more by persons with ASD than persons with typical development [33]. It was hypothesized that these features were critical to understanding facial affect, and the differences in attention in ASD were used to explain difficulties in the recognition of familiar faces and emotion in faces. In the current study, a very similar pattern of attention to facial features was shown, as in [32], where facial features were mostly non-critical and the task was non-social. Combining the results of the current study and the Pelphrey et al. (2002) study [32], this may present more evidence for a facial featural processing difficulty being responsible for differences in facial recognition processes in general, as opposed to a socially-specific difference in emotion detection.

Limitations and Future Studies

A main limitation of the current study was likely the sample size; difficulty recruiting from a rural area of Alabama, for high-functioning participants who could be still during calibration and testing proved difficult. Future plans for research include testing more participants and conducting a mediational analysis (which requires a larger sample) to test the contribution of visual attention to the relationship between diagnosis and implicit learning. Future studies might also look at the role attention plays in other implicit learning tasks, as well as tasks where performance differs for persons with ASD. Investigations of modifying attention (such as explicitly cueing) to specific stimuli and how it may affect the differences seen in implicit learning in persons with ASD would also be interesting.

Conclusion

In conclusion, moderately large, marginal differences in prototype learning were observed for persons with ASD compared to persons with typical development. However, evidence was found that these differences, though small, may have been related to differences in visual attention. Persons with ASD had fewer fixations, especially to the critical varying features. Presumably, not attending to the critical features led to not learning the category prototype as well as those who attended to these features more. This effect may not be specific to ASD, as it was found that persons with typical development who had greater attention toward critical areas also showed larger prototype effects. The present study suggests that the cognitive process responsible for differences in individuals with ASD may not be differences in the ability to implicitly learn. Instead, more general attentional differences may cause persons with ASD to miss critical information that is required to implicitly learn categories.

Declaration of Conflicting Interests & Compliance with APA Ethical Standards

The author declares no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. Additionally, the author has complied with APA ethical standards in the treatment of human participants.

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