Features of Social and Geometric Images and their Effects on Eye Gaze Patterns in Toddlers with Autism

David Conant

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Abstract

Eye tracking has been shown to be a powerful tool for the early identification of autism using a paradigm that evaluates a toddler's preference for geometric or social images (Pierce et al. 2011). In the original study, a subset of toddlers with autism fixated on geometric patterns to a much greater degree than social images and could be accurately classified as ASD based on their looking patterns. It is unclear, however, the factors such as order, salience, or motion of images, that contributed to the strong preference for geometry found in the original study. Using eye tracking technology, 104 toddlers ranging in age between 12 and 48 months participated in a series of experiments that manipulated the order of the geometric or social scenes, the salience and motion of the images used in the original study. Results indicated a minor influence on preference due to stimulus order, as well as a possible influence from number of geometric objects.

Introduction

When considering treatment strategies for Autism Spectrum Disorder (ASD), the importance of early intervention is proving to be especially important for successful outcomes (Dawson et al. 2010; Kasari 2002; Smith 1999; Rogers 1996). However, certain features of diagnosing an ASD using behavior-based diagnostic tests, such as the Autism Diagnosis Observation Schedule (ADOS) makes early identification difficult, especially at younger ages. While the ADOS has proven to be very reliable (Luyester et al. 2010), it requires a thoroughly trained psychologist and a significant amount of time to administer (Perry et al. 2005) (Lord et al. 2000). These features make such an in depth diagnostic test somewhat unfeasible as the sole means of screening for autism, because it would require intensive resources to assess a large population. One possible solution to this problem is to use a screening technique that is fast and cost-effective to identify children at risk for autism, who can then be assessed using more thorough and involved diagnostic testing.

Recent studies show promise that eye tracking technology may meet these needs. Using eye tracking for screening offers several advantages: stimuli are quick and relatively easy to run on very young children, and the results are quantifiable. Many phenotypes of eye gaze have been identified, such as a lack of preference for biological motion or avoiding fixating on faces (Klin et al. 2009; Riby et al. 2009); if properly calibrated, such phenotypes could be used to screen for ASDs. In fact, a new study by Pierce et al. (2011), published in Archives of General Psychiatry, demonstrated that patterns of eye gaze could be used to discriminate toddlers with autism from those that were developmentally delayed (DD) or typically developing (TD). In this study, 110 toddlers ranging in age between 12-42 months sat on their mother's lap as they watched a one-minute movie that contained shapes moving on one side of the screen (i.e., "dynamic geometric images; DGI) and children dancing and doing yoga on the other (i.e., "dynamic social images"; DSI) (See Figure 2). Overall, toddlers with an ASD as young as 14 months spent significantly more time fixating on dynamic geometric images. If a toddler spent more than 69% of his/her time fixating on geometric patterns, then the positive predictive value for accurately classifying that toddler as ASD was 100%. Thus, results indicate that a strong preference for geometric patterns (i.e., > 69% geometric patterns looking time) is robust and specific to autism, largely absent in typically developing, developmentally delayed, or language-delayed groups. A video of the stimulus used, as well as videos of two children's gaze patterns, are available at www.autism-center.ucsd.edu.

Despite the promise of this new screen for autism, it is unclear exactly what features of the video are driving the response. That is, does the order of scene presentation or saliency of an image impact a toddler's preference? At its most basic, a salient feature is something that directs attention. This includes a very broad set of features and can be visual (e.g. color or contrast), auditory (e.g. volume or pitch), emotional, or based on personal experience. Given the overwhelming number of features that could be contributing to the preference for geometric figures among subjects with ASD, it is outside the scope of this study to fully account for every possible feature. Rather, it was our goal to identify those features most likely to be impacting a toddler's attention towards the video. Specifically, in order to examine the impact of salient features on preference, we manipulated each video type (i.e., geometric and social) in terms of stimulus size, motion, and number.

The overarching goal of this study is to investigate the nature of the preference for geometric figures in the hope that we can simultaneously improve the diagnostic power of the stimulus and have the potential to characterize new phenotypes of the gaze patterns of toddlers with autism.

Methods

Participants

As described in our 2011 paper (Pierce et al), subjects were recruited from 2 sources: general community referral (e.g., Web site) and a general population-based screening method called the 1-Year Well-Baby Check-Up Approach (Pierce et al. 2011(2)). Using this method, toddlers at risk for an ASD as young as 12 months were identified with a broadband screening instrument, the Communication and Symbolic Behavior Scales Developmental Profile Infant-Toddler Checklist, (Wetherby et al. 2002, 2008) and were recruited and tracked every 6 months until their third birthday. This method thus allowed for the prospective study of autism beginning at 12 months of age. Typically developing controls were obtained from community referrals. All toddlers participated in a series of tests across multiple 2-hour sessions that included the Autism Diagnostic Observation Schedule–Toddler Module (ADOS-T), newly validated for use with infants as young as 12 months (Luyster et al. 2009), and the Mullen Scales of Early Learning (Mullen et al. 1995). Parents were also interviewed with the Vineland Adaptive Behavior Scales (Sparrow et al. 1984). Toddlers participated in additional behavioral (e.g., play) and biological (e.g., magnetic resonance imaging) tests as part of a larger study. (For more information, see www.autism-center.ucsd.edu). All standardized assessments were administered by 3 highly experienced PhD-level psychologists with more than 10 years combined experience in autism. Overall, 104 toddlers aged 12 to 48 months participated. 37 were excluded from final analyses because of noncompliance during testing, which almost always resulted in less than 50% valid trials. The final group of 73 toddlers consisted of 26 with an ASD, and 37 as TD. Not all toddlers included in the analysis were run on all stimuli. Toddlers diagnoses other than TD or ASD (e.g. Developmental Delay, Language Delay) were not included in this study because data was collected on too few. However, our previous study has shown that these groups do not perform significantly differently from the TD group on this paradigm (Pierce et al 2011). This study was approved by the University of California, San Diego Human Subjects Research Protection Program. Legal guardians of all participants gave written informed consent.

Stimuli

Preliminary Stimuli Analysis

In order to provide insight into what sorts of features are particularly relevant, a scene-by-scene preference analysis was done in which each scene of the video was taken independently of the others and its average preference calculated. Scenes with particularly high or low discriminatory power (i.e., the degree of difference between ASD and typically developing

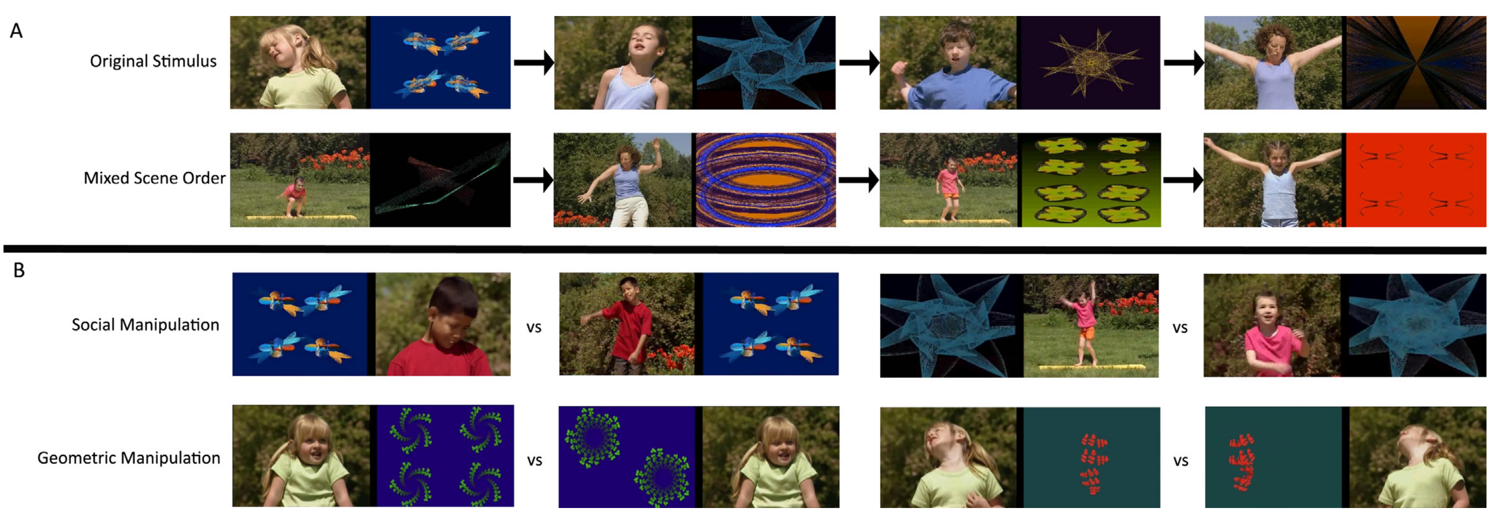


Figure 1: Example Frames From Stimuli
A) The mixed scene order video features the same content as the original stimulus, but in a different order. Shown are the first 4 scenes from each video. B) Example of control pairs in the social and geometric manipulation stimuli.

groups) were isolated in order to identify potential features that may be driving the preference. However, this analysis alone only provides speculation; this evidence is not sufficient to conclude which features are important or their degree of importance because the features were not shown in a controlled setting. In order to control for individual features of the original stimulus, we made three new videos that seek to control for various features that may be driving preference.

Mixed Scene Order

Because the original video features sequences of scenes with similar content (e.g. the same action was done in every scene for five scenes in a row), we wanted to understand how scene order might influence the preference. In this first video, which we dubbed “mixed order”, the order of the scenes in the video is shuffled such that the content of each scene is independent of the preceding and following scenes (Fig 1A).

Geometric Manipulation

In the second video, which we called “geometric manipulation”, the social stimulus is the same as the original, but the geometric side has been replaced with a stimulus that controls for individual features. These features include size of the geometric object, translational motion, expansion or contraction, and number of geometric objects. New geometric stimuli were made using Apophysis, a fractal creation toolkit (http://www.apophysis.org). New stimuli were made in pairs such that each of the pair exhibits the same feature to a different extent. For example, if the pair seeks to control for translational movement, one of the figures moves across the screen while the other remains stationary. Each of these pairs was then shown in conjunction with the same social

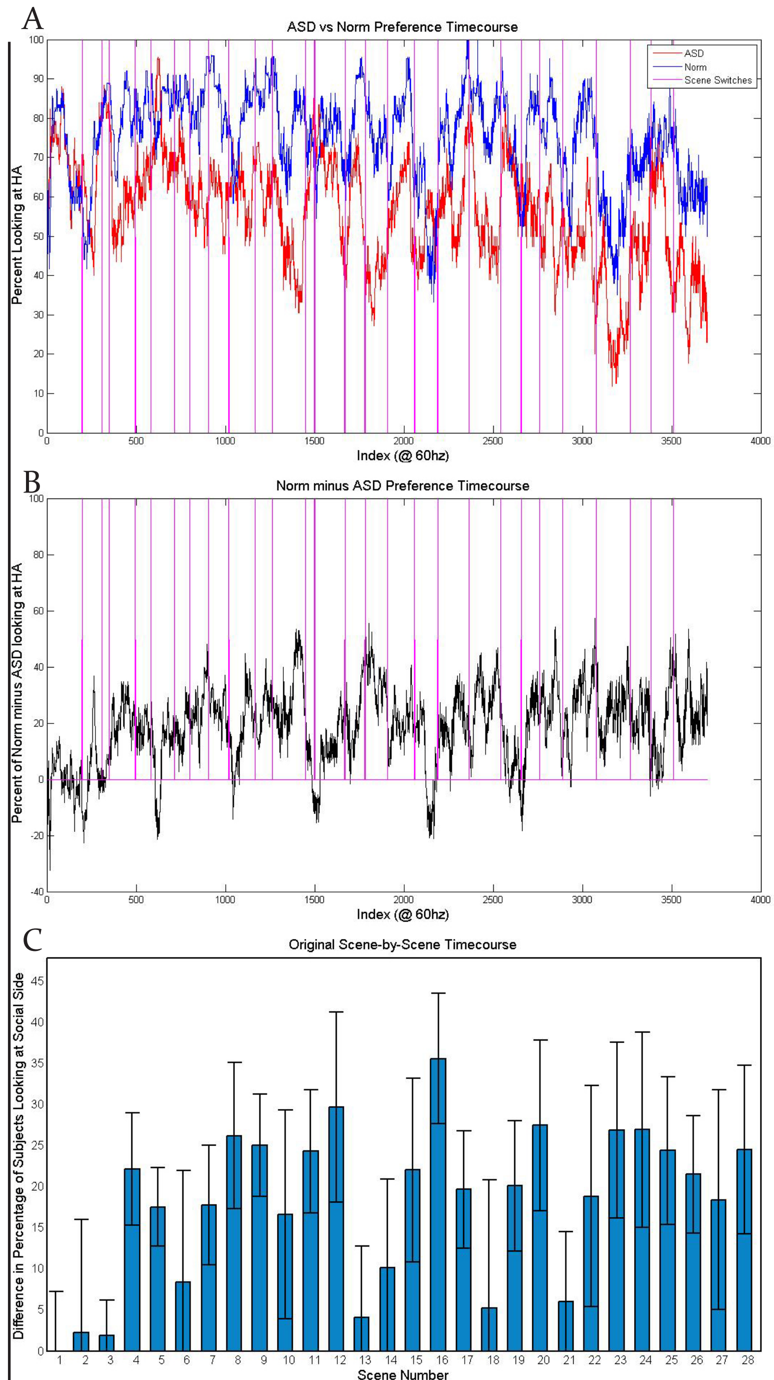


Figure 2: Results from preliminary analysis of Original Scene

A) Timecourse preference plot showing percent of subjects looking at the social side plotted against time.
B) The difference between the ASD and TD groups (TD minus ASD) from A plotted against time.
C) Taking the average across scene lengths from B provides a scene by scene average difference in preference.

stimulus such that the only difference between the two conditions was the manipulated feature (Fig1B).

Social Manipulation

The final video, called "social manipulation", featured the same geometric stimulus as the original, but with different social scenes that controlled for various features. These features include the size of the actor in the frame, the degree to which the actor is moving in the frame, and whether the actors are interacting with the camera or with one another. These new social scenes were taken from the same video as the original (Yoga Kids 3; Gaiam, Boulder, Colorado, http://www.gaiam.com, created by Marsha Wenig, http://yogakids.com), with the same actors, but none of the original scenes were used. In the same manner as with Geometric Manipulation, the new stimuli were each counter-balanced with the same geometric scene so that the only difference between the two conditions was the manipulated feature (Fig 1B).

Presentation and Data Collection

Data collection procedure was the same as described in our 2011 paper, reproduced here. The newly created videos were shown to toddlers (age 12-48 months) while a Tobii T120 eye tracker (Tobii, Danderyd, Sweden, www.tobii.com) recorded the location of their eye gaze. The toddlers sat on the lap of a parent while watching the video. So as not to bias the results, the parent was instructed not to point at or verbalize any aspect of the stimulus. The binocular eye tracker used infrared light sources and cameras that are integrated into a 17-inch-thin film transistor monitor. Using corneal reflection techniques, the Tobii eye tracker records the X and Y coordinates of toddlers' eye position at a frequency of 120 Hz (ie, 7200 data collections/min). Two additional small cameras were placed on top of the eye tracking monitor to obtain video of each toddler's behavior during the experiment at all times.

Dependent Variables and Analyses

Eye tracking data was exported into Matlab (Mathworks Inc. 2011), which was used for all data analysis. First, data was filtered to exclude timepoints in which eye tracking quality was less than satisfactory as recommended by the eye tracker manufacturer, as well as any points when the subject was not looking at the video. Based on these criteria, any subjects that had fewer than 50% valid samples were removed from further analysis. To determine preference, the side to which a subject was looking (social or geometric) was determined for every recorded eye tracking sample while the stimulus was being shown.

Comparison of Percent Time Viewing

For the analysis of the "mixed order" condition, it was important to know how changing the scene order affected the overall preference, which was the primary metric used in the original study (Pierce et al 2011). To accomplish this, each subject's preference was averaged across the entire stimulus, resulting in a simple percentage of time that each subject spent looking at the social side of the video. These values were then separated by diagnostic group and plotted in a two-dimensional scatterplot (Fig 3). Significance between groups was determined using a 1-way analysis of variance (ANOVA).

Scene-by-Scene Timecourse

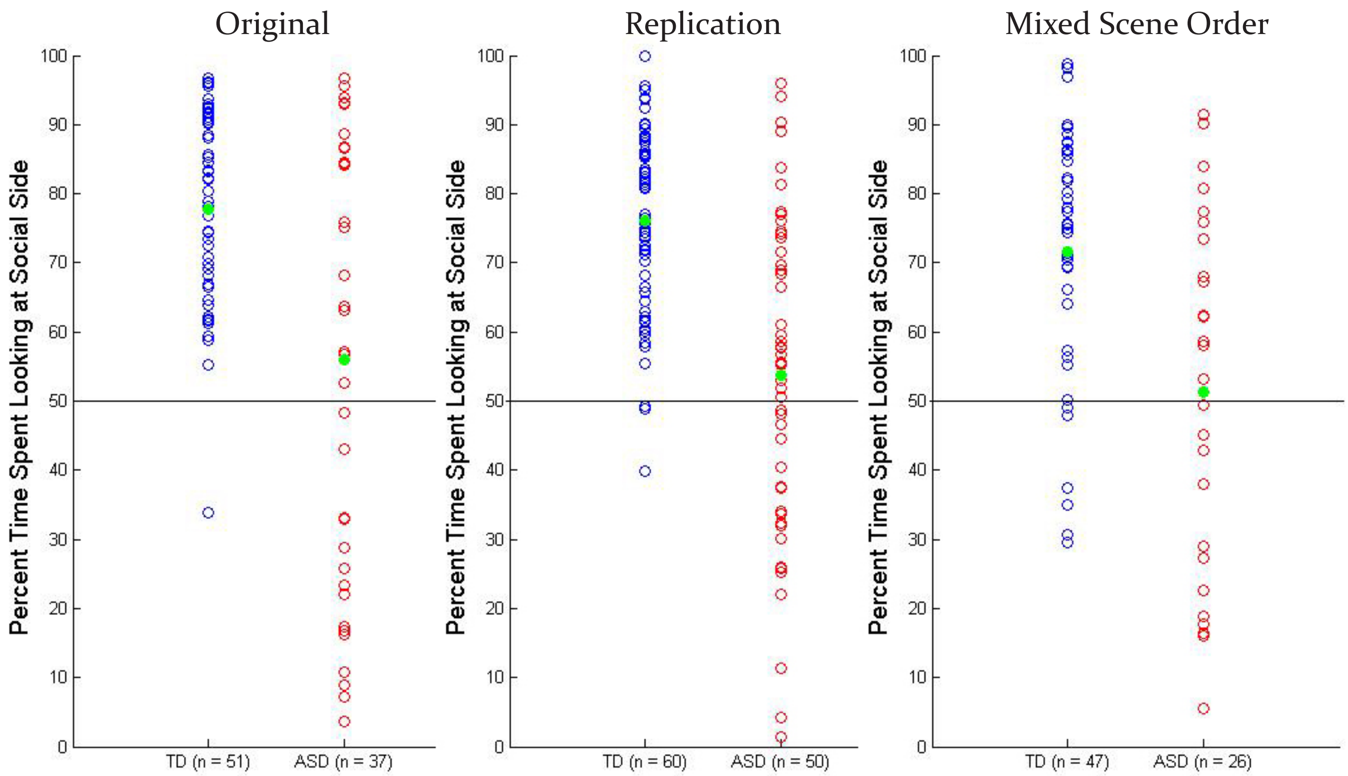


Figure 3: Preference scatterplots of the original, replication, and mixed scene order datasets.
The 0riginal and replication are extremely similar, but the mixed scene order features a modest downshift in social preference for the TD group but not the ASD group.

In order to investigate how preference changes with time, this data was then averaged across participants within each diagnostic category (ASD and typically developing) to give a diagnostic group average preference for every timepoint. At this point, the data can be shown as a group preference timecourse graph by plotting the average preference for each group against time (for example see Fig 2A). While this is a very effective way to visualize the data as a whole, it is difficult to quantify the effect that an individual scene has on preference. To accomplish this, the group preferences were averaged across scenes, resulting in a single number to represent preference for each scene. To compare between diagnostic groups, preference values for each scene for the ASD group were subtracted from the TD group (for example see Fig 2C). Comparison of scenes was done using a 1-way ANOVA.

For the analysis of geometric and social features, the timepoints in which a figure first appeared were compared to when it later appeared with an altered salience feature in order to determine the effect that the feature had on the group preferences (Fig 5).

Results

Original Stimulus

Although analysis of the original stimulus is limited in potential results, a scene-by-scene timecourse yields one important observation. There is great variability of preference among the scenes, indicating that there seems to be some factor or group of factors that vary in the individual scenes that has an effect on preference. This is not a surprise, but this information validates the method of analyzing the scenes independently in order to investigate factors that affect prefer-

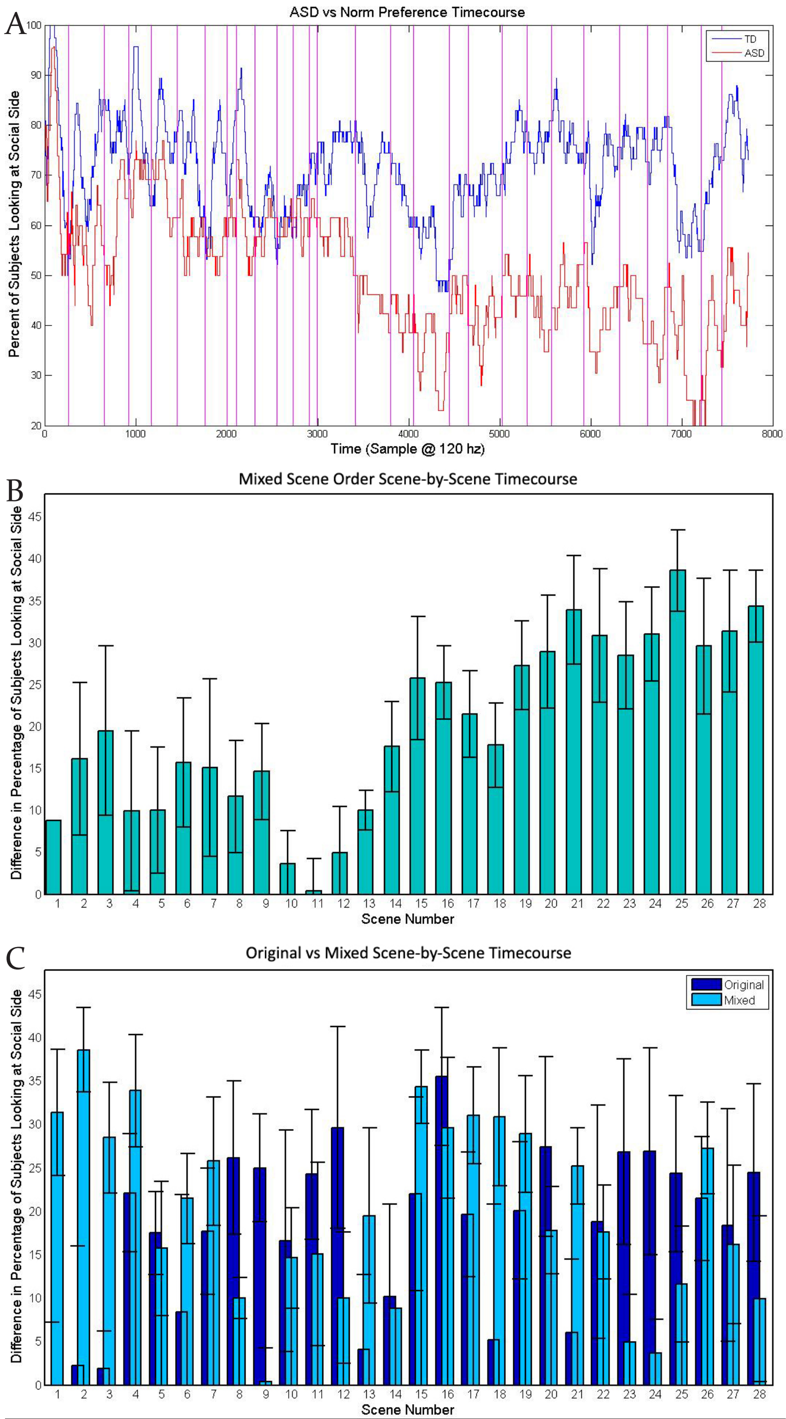
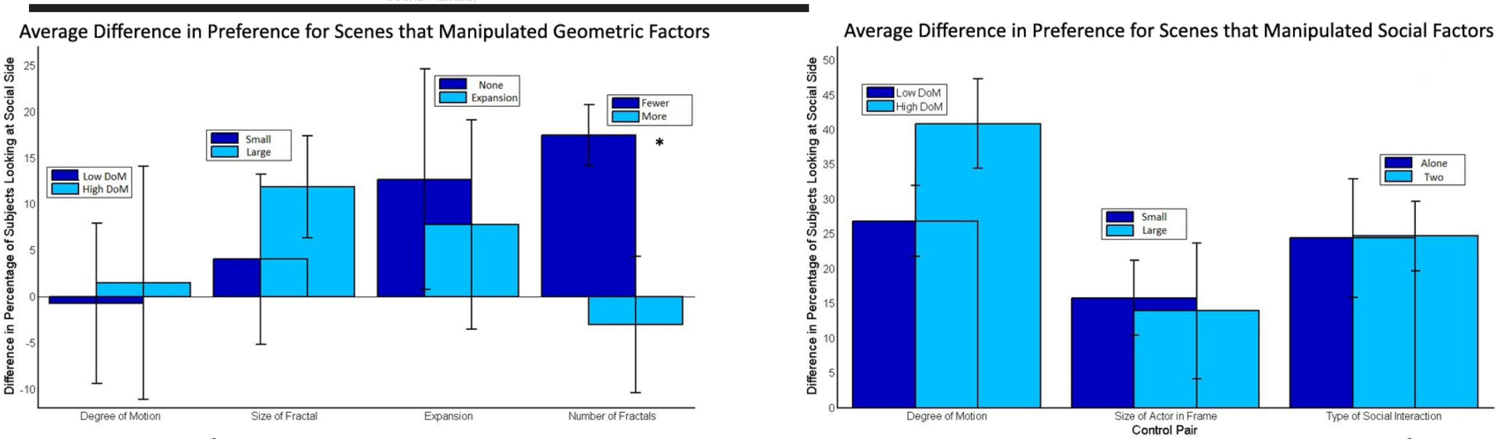


Figure 4: Timecourse preference results from the mixed scene order dataset

A) Timecourse plot showing percent of subjects looking at the social side plotted against time.

B) Difference between TD and ASD groups (TD minus ASD) from A, averaged across scenes, resulting in a scene-by-scene preference timecourse

C) Data from B plotted against the equivalent scenes from the original study. Although the overall average magnitude is not very different, there is significant difference when analyzing on a scene-by-scene basis.



n = 14 TD and 7 ASD

n = 15 TD and 8 ASD

Figure 5: Average difference in preference that resulted from manipulation of social and geometric factors

Graphs depict the average difference in preference (similar to that shown in figure 4C), averaged across all scenes that manipulated a given factor. For example, scenes 8, 14, 23, and 32 depicted a geometric figure that was comparatively large, and thus the average difference in preference for these scenes is depicted.

ence.

Scene Order Effects

The overall preference of subjects shown the "mixed order" stimulus was slightly shifted towards the geometric side, but not significantly different from the original for either the TD (p = .098) or ASD (p = .213) groups and the effect between groups remains robust (p = .00015). However, there were significantly more subjects in the TD group that preferred the geometric side (Fig 3). While this did not significantly affect the mean or distribution, it is relevant when considering how the stimuli are able to screen for ASDs as these outliers would be considered false positives.

Analyzing further, comparing the scene-by-scene preferences of the mixed scenes to their original counterparts shows that shuffling the scenes did result in a different degree of preference for individual scenes (p = .014) (Fig 4).

Social and Geometric Manipulation

Of the seven factors tested in total, only the number of geometric objects proved to play a significant role in preference (Fig 5). Scenes that depicted fewer objects on the geometric side resulted in more TD subjects looking at the social side of the stimulus relative to the ASD group. In other words, there was a stronger diagnostic effect when fewer geometric objects were shown (Fig 5). While this result proved significant (p = .049), it should be noted that at this time relatively few subjects have been run on the social and geometric manipulated paradigms, and thus this finding should only be considered preliminary (Fig 5).

Discussion

Using a simple one-minute test, toddlers with autism again showed a clear preference for geometric patterns as has been demonstrated by our earlier work. However, this effect appears to be impacted somewhat by the order of the stimuli shown. Specifically, for the current study, the preference for geometric patterns in ASD remained almost identical to the original study. The TD toddlers, however, showed a somewhat lower preference for social images than the original study. Furthermore, individual scene analysis showed that scenes did not retain their preference when their order was shuffled. This makes some intuitive sense. In the original video, the social side of the video featured a logical progression of events. When the order was shuffled, this progression was removed and made the social stimulus scene transitions nonsensical. This implies that typically developing toddlers as young as 12 months old may be able to recognize the scene progression, while toddlers with an ASD are not.

Results of the present study also found a trend for the number of geometric images as being relevant to the preference. Typically developing toddlers were much more likely to look at the social stimulus when the geometric side had more objects (greater complexity) than when there were fewer objects. The preference for those toddlers with an ASD, however, did not exhibit this feature. Due to a small sample size at this time, this result should only be considered preliminary.

As the epidemiology of autism becomes better understood, and early intervention strategies become more successful, it will be crucial to be able to identify autism early in life. This work, and work to come, can contribute to making the stimuli more diagnostically powerful and ultimately improve the success rate of future tests that screen for autism at a very young age.

Overall, this study provided insight into the motivations and factors that impact typically developing toddlers to a higher degree than it informed us regarding those with an ASD. While this means we are unable to characterize any new phenotypes of autism, it is nonetheless useful for improving our screening stimuli.

Overall results from this study confirm that toddlers at risk for, and confirmed ASD, have a strong preference for geometric repetition. It is clear from this work that future rapid screening and eventual diagnostic procedures could incorporate this simple test.

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