Analysis of Autism Spectrum Disorder and Metrics of Eye Movement

Ethan S. Yun
Stanford Online High School
Redwood City, CA 94063, USA
ethansyun@icloud.com

Abstract

This paper studies the relationship between eye movement and autism spectrum disorder (ASD), a comparison that can be easily made in most homes with current advances in AI and basic webcam technology. Diagnosis of autism spectrum disorder in children is an important and difficult task which is crucial for children who need treatment or aid. Therefore, it is optimal that people take advantage of modern technology to create accessible methods of diagnosis that are reliable. The data studied is a dataset of images and the eye traces of children with ASD and children without ASD who viewed the images. Weighted distance variance, a measure of how variable eye movement is, is calculated using trace data that has a gaussian filter applied. Additionally, the mean brightness and variance of brightness in the images are also calculated. The weighted distance variance is compared for the children with ASD and the children without ASD. The two groups are also compared by their reactions to the brightness of the images. The data analysis reveals that variableness of eye movement can be used to differentiate children with ASD and children without ASD. However, the two groups' reactions to image brightness are found to be indifferentiable.

1. Introduction

The diagnosis of autism spectrum disorder (ASD) in children is an important task, as it allows children with ASD to get adequate and appropriate treatment during the developmental stages of their life. Current diagnosis techniques include monitoring the subject's behavior throughout childhood and beyond, but there are no medical tests for ASD (CDC 2021). Treatments for ASD include cognitive behavior therapy and nutritional therapy, but are not standardized and can vary from person to person (NICHD 2021). With early diagnosis and treatment, autistic children can more effectively make progress against ASD and even completely move themselves off the spectrum later in life (NICHD 2021). However, many children go undiagnosed until they are older, and often do not get as many resources for their disability (Wiggins et al. 2019). Especially in children of minority groups, the accuracy and thoroughness of diagnosis is often less than the quality of diagnosis that white children receive (Wiggins et al. 2019). Additionally, the diagnosis of autism spectrum disorder is a complex ordeal that could span months and years, which can leave the few unlucky to remain undiagnosed until they are much older.

The purpose of the project is to study the variableness of eye movement and the brightness of the observed images, and whether they are behavioral indicators of ASD. With current technology and software, eye movement is relatively simple for people with access to technology to measure. Therefore, by thorough analysis of eye movement, the diagnosis of ASD in children could become more accessible to people, as it could be done directly in homes instead of at clinics and in tedious evaluations. Current research on the topic focuses on how trace paths of eye movement can be used to detect ASD. With deep learning models being used to diagnose ASD (Xie et al. 2019) and models using eye trace maps to analyze how often the subject makes eye contact (Solovyova et al. 2020). Moreover, convolutional neural networks, models that specialize in analyzing image data, have been used as well to give accurate and fast diagnoses of ASD (Fernández et al. 2020). This paper instead analyzes the isolated variable of the variableness of eye movement in relation to ASD and focuses on how the variable can be used to differentiate between children with ASD and children without ASD. Separate from previous research, this paper does not give a model for diagnosing ASD, but instead hopes to demonstrate why and how the variableness of eye movement can be used by predictive models to diagnose ASD.

2. Methods

The raw data consists of images with their corresponding fixation maps, which are just mappings of eye movement across the images. The fixation maps have a gaussian filter applied in order to account for the possible errors in eye tracking. In order to successfully prepare the collected image data for analysis, one needs to apply calculations to each filtered fixation map, which will generate the weighted distance variance of each fixation map, the weighted mean of each fixation map (estimated center of the fixation map), the average brightness of each image, and the variance of the brightness of each image.

2.1. Research

The image data that is analyzed in the paper contains eye fixation maps with a gaussian filter applied. The eye fixation maps are black images with white points that indicate the point of focus on the corresponding images which were viewed by the children (Figure 1). The gaussian filter introduces a level of uncertainty to the eye movement in order to account for possible errors in eye tracking (Figure 2). The gaussian filter is needed, as eye trackers that can be found online and used in homes will in most cases make small mistakes about the fixation of the eye. As this project hopes to help researchers make diagnosis more accessible, it is necessary that we account for the quality of eye trackers that most people will have access to.

Figure 1: Fixation map without gaussion filter

Figure 2: Fixation map with gaussian filter applied

2.2. Hypotheses

The null hypothesis for the data analysis on each aspect of eye movement would be that there is no difference between that aspect of eye movement in children with ASD and in children without. The alternative hypothesis would be that the children with ASD would exhibit different aspects of eye movement in comparison to children without. Some aspects would be variability of eye movement, or how erratic eye movement is, and how sensitive the eye movement is to brightness. The variability of eye movement would be measured by the weighted distance variance of the fixation maps. The sensitivity of eye movement to brightness would be measured by how correlated the mean and variance of brightness of the images are to the weighted distance variance. It has already been proven that children with ASD tend to have different patterns of eye movement than children without. For instance, children with ASD have been observed having a harder time making eye contact (Solovyova et al. 2020). Therefore, considering the current consensus on the relation between eye movement and ASD, it is very plausible that every aspect of eye movement relates to ASD in some fashion.

2.3. Data Collection

The data was collected by researchers who selected two groups, 14 subjects with ASD and 14 subjects without. The ages of the children in the two groups ranged from 5-12 years old, and their eye focus was traced across an image using the Tobii T120 eye tracker (Duan et al. 2019). The children observed the images for 3 seconds, with 1 second grey-screen intervals in between. In total, 300 fixation maps were collected from the children in each group, corresponding to 300 different images. The data used in this study was extracted from the fixation maps provided. The four variables that were gathered were the weighted distance variance of each fixation map, the weighted mean of each fixation map (estimated center of the fixation map), the average brightness of each image, and the variance of the brightness of each image. The weighted mean was used simply to find the weighted distance variance, which was used as a measure of how erratic the subject's eye movement was on the particular image. The weighted mean represents the general center of focus of the eye movement, while the weighted distance variance represents how spread out the eye movement is over the image. The weighted mean of each fixation map was calculated by treating the brightness of a pixel as its weight (brightness from 0-1, similar to lightness in HSL coloring) and using it to calculate the weighted mean position of every pixel in the image. Similarly, the weighted distance variance of each fixation map was calculated by treating the brightness of a pixel as its weight and using it to calculate the weighted distance of each pixel from the weighted mean. The average brightness and the variance of brightness of each image was used in conjunction with the weighted distance variance to determine whether the brightness of the images had any effect on the eye movement. The average brightness shows how bright the image is overall, while the variance of brightness shows how drastic lighting is in the image. The average brightness and the variance of the brightness of each image was calculated by converting the images to grayscale and then calculating the mean and variance of a single RGB band.

3. Data and Analysis

Before the analysis, all the variables in data collection were aggregated into a single dataset and the numpy python library was used to perform the statistical tests. The analysis tested three different indicators of eye movement with the two-sample t-test and the spearman rank correlation coefficient (SRCC). First, the 2-sample t-test was used to determine whether there was a difference between the weighted distance variance in the ASD group and the TD group (children not diagnosed with autism spectrum disorder). Secondly, the SRCC measure was used to test whether the two groups reacted differently to images of different levels of brightness and different ranges of brightness.

3.1. Data Presentation

A histogram was used to visualize the distributions of the weighted distance variance in both the ASD group and the TD group (Figure 3). The histogram shows a slight difference in the distributions for the weighted distance variance of the ASD group and the TD group, indicating that the t-test might return a statistically significant result. Additionally, the histogram shows that both the distributions of the weighted distance variance for both the ASD group and the TD group are roughly normal. For the correlations between average brightness and variance of brightness with the weighted distance variance, a scatterplot was used to visualize the data, so that any correlations might be indicated with a rough line of points (Figures 4 and 5). The scatterplots do not seem to have any discernable trend, which might indicate that the tests will return statistically insignificant or weak results.

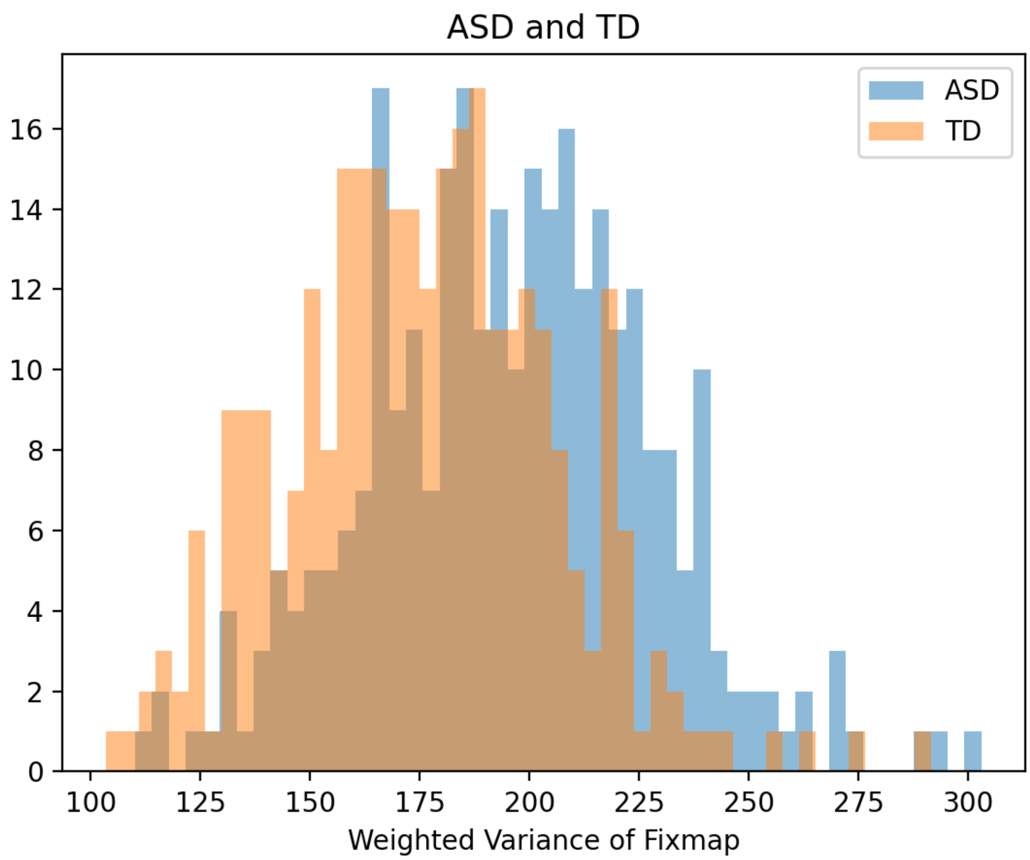

Figure 3: The Weighted Variance of Fixmap is measured in units of pixels. Specifically, the weighted variance of the fixmap is the weighted average distance from each pixel to the weighted mean of the fixmap.

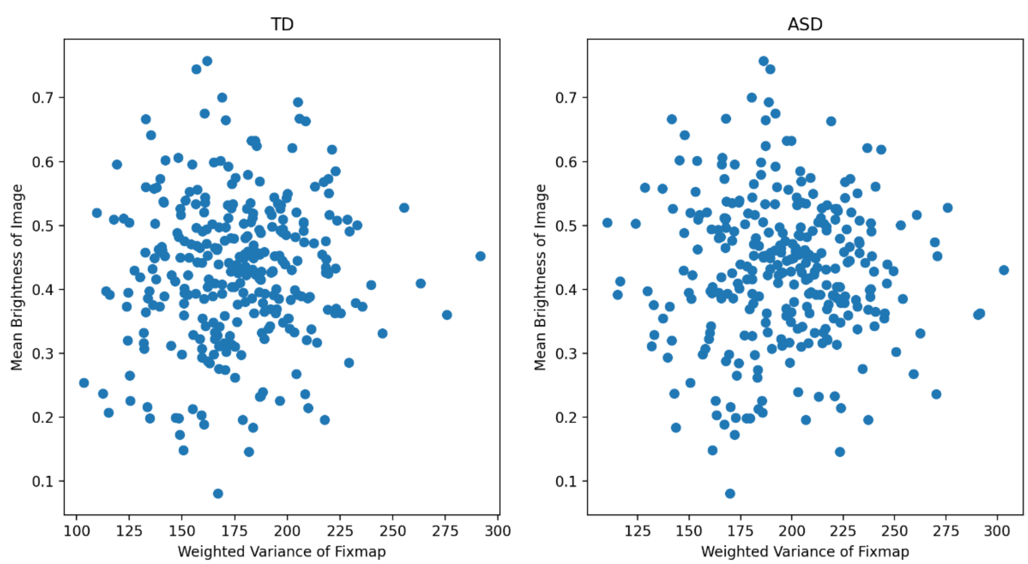

Figure 4: From left to right, r=0.056 and r=-0.016

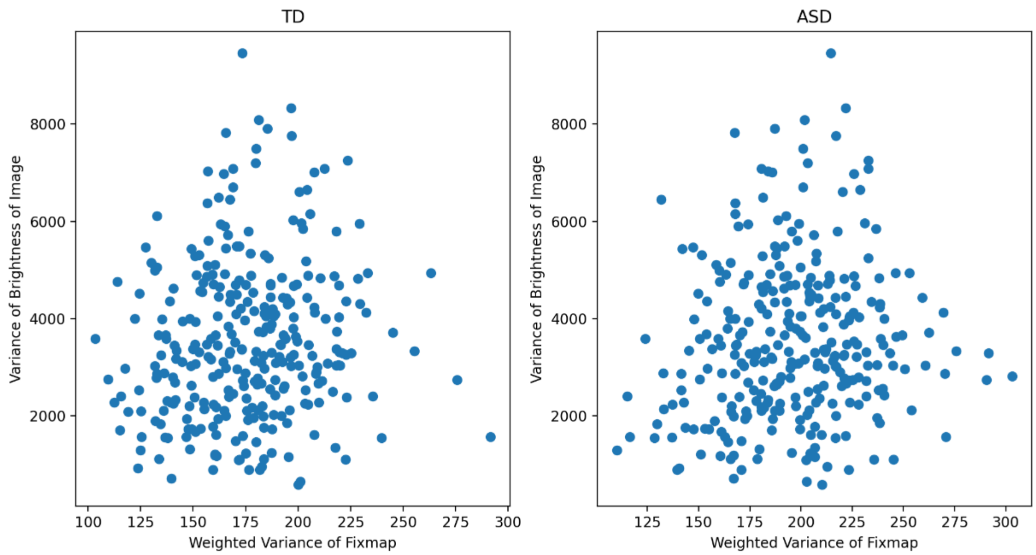

Figure 5: From left to right, r=0.128 and r=0.120

3.2. Differences in Erratic Eye Movement Using the 2 Sample T-test

To test whether the eye movement of the ASD group (children diagnosed with autism spectrum disorder) was different from the eye movement of the TD group, the weighted distance variance of the fixation maps in each group were compared. The independent two-sample t-test was used to compare the groups, as the distribution of both samples were approximately normal, as indicated by the histogram, which meant that the data was suitable for a parametric test (Figure 3). The result of the t-test yielded a statistically highly significant result of $t = 7.87$ ($P = 1.64 \cdot 10^{-14}$), meaning that there is a difference in the weighted distance variance of the ASD group and the group without ASD. The P-value of the test was lower than the standard 1% marker for statistically highly significant results, meaning that there was a negligible chance of the difference between the two distributions being due to randomness. More specifically, as the histogram of the two groups indicate, the group with ASD seems to overall have more erratic eye movement (higher variance in fixation map) than the group without ASD. Therefore, the variability of eye movement would be a helpful metric for differentiating between children with ASD and children without, which would make it a helpful feature use when diagnosing children for ASD.

3.3. Reactions to Levels of Brightness in Images Using SRCC

An additional set of tests were done to see whether the brightness of the image had any impact on the eye movement of the two groups, as expected. The impact that brightness had on eye movement was measured to see whether there were different impacts for children with ASD and for children without ASD. It was tested whether the variance of eye movement of either of the two groups correlated with the mean brightness of the images or not (Figure 4 and 5). The same tests were repeated for a correlation test between the eye movement of the two groups and the variance of the brightness of the images (Figure 4 and 5). The Spearman Rank Correlation Coefficient test was used to measure the monotonicity of the relationships, as there was no clear guarantee of the data being linear, and the goal was to simply determine a possible relationship.

The two tests comparing the mean brightness of the images and the weighted distance variance returned statistically insignificant results of $r_{ASD} = -0.0165$ ($P_{ASD} = 0.776$) and $r_{TD} = 0.0557$ ($P_{TD} = 0.337$), meaning that there is no monotonic correlation between the average brightness of an image and the weighted distance variance of eye movement. The results showed that any possible monotonic correlation would likely be due to the randomness of the data, as indicated by the fact that both P-values were well above the 5% marker for statistical significance. Therefore, it was shown that the overall brightness of an image likely had no effect on how erratic the eye movement was, which was true for both the ASD and TD groups. Both the children with ASD and the children without reacted in the same way to brighter images and dimmer images. The result went against the earlier hypothesis that childrens' reactions to the overall brightness of images would be different for children that have ASD when compared to the reactions of the children without ASD. Ultimately, the visual reaction that children had to the brightness of the images would not be helpful for differentiating between children with ASD and children without.

The two tests comparing the variance of brightness of the images and the weighted distance variance returned statistically significant results of $r_{ASD} = 0.120$ ($P_{ASD} = 0.0376$) and $r_{TD} = 0.128$ ($P_{TD} = 0.0261$). However, for the test regarding the variance of the brightness of the images, the P-value results were disregarded since the correlation coefficients were very weak and as there was no visual indication of a correlation. So, the analysis concluded that the childrens' reactions to images of greater or lesser variance in brightness were likely the same, which was reflected in both the ASD group and the TD group. Since the results of the test were the same for both groups, it was again concluded that the visual reaction that children had to the variance of brightness of the images would not be helpful for drawing a distinction between the ASD and TD groups.

Overall, the analysis regarding brightness of images showed that sensitivity to brightness was not affected by ASD. Considering all correlation coefficients were weak or insignificant, it was reasonable to say that the eye movement of the children did not depend at all on the brightness of the images. The relationship between the brightness of the images and the variability of eye movement would not be helpful for diagnosis.

4. Conclusions

From the results of the analysis, the conclusion can be made that there is indeed an association between erratic eye movement and ASD. When comparing the distributions of the weighted distance variance of the children that had ASD and the children without ASD, a highly significant result of $t = 7.87$ ($P = 1.64 \cdot 10^{-14}$) was returned. This indicates that weighted distance variance could be used as a helpful measure of erratic eye movement to draw the distinction between children with ASD and children without. For brightness and eye movement, the difference between the two groups was not realized by the data. In the tests on the correlation between mean brightness of image and weighted distance variance, the tests for both the ASD and non-ASD group returned statistically insignificant results of $r_{ASD} = -0.0165$ ($P_{ASD} = 0.776$) and $r_{TD} = 0.0557$ ($P_{TD} = 0.337$), meaning that there was no helpful distinction that could be drawn between the two groups using the mean brightness metric. Similarly, for the same tests performed on the mean brightness of image and weighted distance variance variables, significant but very weak correlation coefficients of $r_{ASD} = 0.120$ ($P_{ASD} = 0.0376$) and $r_{TD} = 0.128$ ($P_{TD} = 0.0261$) were returned. It was found for both correlation tests that the mean brightness or variance of brightness of the images could not be useful for separating the ASD and non-ASD group for predictions, as the tests returned similar results for both groups. So, comparing the eye movement with relation to the brightness would not be helpful for making predictions or drawing distinctions between children with ASD and children without ASD.

5. Future Research

Future investigations of this project could gather more data with more children, which would make the sample more reflective of the population. Possible sources of error in the current analysis could come from biases in the sample itself, as a group of 14 children does not seem to completely encompass the population of children. Some questions to ask for future researchers would be whether there is a better way to analyze the eye movement of the children, other than using simple weighted variance. Future investigations could be done to answer questions about whether eye movement is a good indicator for diagnosing autism in children, compared to current methods. Determining whether the eye movement can be tracked and analyzed in real time would be an interesting follow-up to the current project. Moreover, similar analysis could be applied to different sources of data, such as features of the images instead of simply the behavior of eye movement (He et al. 2021).

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