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The Role of Color in Face Processing and Autism Spectrum Disorders

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Abstract

The contribution of color in relation to face processing is poorly understood, despite the critical role of face processing in adaptive human interaction and social communication. Both faces and color are particularly salient cues necessary for navigating the environment. This project examines how the typical fixation behaviors employed for face processing are affected by the removal of color. Previous studies using eye-tracking have predominantly used achromatic stimuli, ignoring the role of color in face perception. Furthermore, given that face processing is disrupted in Autism Spectrum Disorders (ASD), investigation into how gaze behavior is affected by color in relation to ASD symptoms is critical to understanding the nature of observed deficits in social communication. We use the Broad Autism Phenotype Questionnaire (BAPQ) to explore the contribution of ASD-related behaviors in a neuro-typical population. Results indicate that the removal of color from images of faces is associated with increased fixation on the eyes of grayscale faces over normal, color faces. Exploratory correlations with BAPQ scores reveal that this tendency is enhanced in subjects with higher (more ASD-like) scores than those with lower scores, suggesting that color provides social information that influences overall fixation time on the eyes.

Introduction

Faces provide a wealth of social information that allows humans to recognize and identify individuals, gain insight into their emotional state, level of engagement, and where they are looking. This social information allows viewers to intuit others' internal states and better predict their behavior. Humans demonstrate an attentional bias towards faces from infancy, which grows stronger throughout development (Frank et al., 2009). Eye-tracking, electroencephalography (EEG), and functional magnetic resonance imaging (fMRI) studies

demonstrate that typically developing humans are particularly attuned to faces, viewing and processing them differently than other objects. Human observers perceive faces in a holistic manner, as a single object with interconnected features or parts, rather than as separate features (Tatler et al., 2010). The ability to recognize faces holistically allows most typical observers to focus on regions of the face, such as the eyes, that provide for more nuanced social information. The eyes allow observers to discern emotional expression, identity, and gaze direction towards salient features in the environment (Emery, 2000).

Color is a key saliency factor in visual perception (Itti et al., 1998), and evidence shows that color in faces provides critical social information such as gender (Nestor & Tarr, 2008), age (Fink et al., 2006), and overall state of health (Stephen et al., 2009). Most important to gaze behavior, color provides social information about emotional state (i.e. blushing with embarrassment, pale with fear). Despite this, color seems to offer little support in face recognition and detection (Kemp et al., 1996; Bruce & Young, 1998; Yip & Sinha, 2002). Perhaps because of this and the notion that color might be a confounding or complicating variable, most studies exploring face processing use achromatic stimuli, and no studies to-date have explored eye-tracking patterns to faces presented in both grayscale and color, though color may provide important social information that could influence gaze behavior.

It is unknown what effect color manipulations may have on stereotyped facial gaze patterns. If removing color degrades facial saliency, for instance, then grayscale face stimuli may necessitate longer fixations on the eyes, relative to unaltered faces. To date, this question remains unexplored in the literature. Understanding how color influences facial gaze patterns is crucial to our understanding of face perception, identification, and emotion recognition (Sinha et al., 2006). Moreover, understanding how color affects facial gaze patterns in healthy neuro-typical

populations may provide insights into mechanisms and potential therapies for individuals with neurological disorders. Autism Spectrum Disorders (ASD), for example, are characterized by a marked reduction in fixation on the eyes of faces (Klin et al., 2002). Studying the role of color in face perception in these populations may inform the nature of observed disruptions in gaze behavior and social communication.

My study explores the effects of color on the tendency of healthy, adult individuals to fixate on the eyes of faces, and how differences in gaze behavior (of faces depicted in color or grayscale) may relate to the ASD phenotype. Removing color from faces may necessitate longer dwell time on the eyes due to the decreased social information available in grayscale faces, and this effect may be enhanced in populations with ASD and those with subclinical ASD traits. This study offers findings on the mediating effects of color on facial gaze behavior, and given that individuals with ASD often avoid fixating on the eyes, the results from my study also translate into direct hypotheses for future studies in ASD populations.

I. Face Perception

Face processing is a highly adaptive capability critical to social interaction. The evolution of social gaze can be traced to animals living socially, which likely necessitated increased reliance on visual signaling in the process of distinguishing in-groups and out-groups and understanding social interactions (Parr, 2011). While social gaze encompasses deciphering visual cues beyond the eyes, such as body posture, orientation, and other facial clues, the eyes are the most important components of the face in determining social information (Emery, 2000). Evidence for the evolutionary importance of eye contact is present in non-human vertebrates, as part of a predator detection system. Animals avert their gaze from the simple schematic of two

dark circles in a horizontal, eye-like orientation, suggesting the vital nature of eye recognition (Coss, 1978). Further, primates have evolved an elaborate facial musculature and a reduction in facial protrusion to support social gaze (Emery, 2000). Studies with monkeys have shown that, regardless of species, subjects show an extreme bias in looking at the eyes and the surrounding area, far more than the nose and mouth (Keating & Keating, 1982). While primates show an attentional bias towards faces and eyes, this bias may not be indicative of the ability to infer another's mental state, although evidence shows that primates do use eye contact to communicate emotional states or the presence of objects in the environment (Emery, 2000). In humans, however, evidence shows that information present in the eyes is critical to understanding facial expressions (Baron-Cohen et al., 1997) and responding appropriately, a concept that will be explored in depth in the following sections.

The evolutionary significance of face perception has led to the development of brain areas in both humans and macaques dedicated to face processing. In macaques, functional magnetic resonance imaging (fMRI) studies have revealed cortical regions where visual cells are entirely face-selective, in that they are significantly more responsive to faces than to other objects (Tsao et al., 2003). These regions are thought to be non-human primate analogues of the superior temporal sulcus (STS) and the fusiform face area (FFA) in humans, which are considered domain-specific areas for face perception. FMRI studies in the mid-1990's revealed that regions of the fusiform gyrus, since considered the FFA, are more responsive to faces than they are to other stimuli like flowers, houses, and words (Kanwisher & Yovel, 2006). The amygdala has been implicated in fMRI studies involving faces depicting fear, and other regions, including the STS and the occipital face area (OFA) have been implicated in face processing.

However, the FFA is the most consistent and robust candidate for a face-specific brain region in humans.

In addition to fMRI evidence suggesting the importance and specialization of faces in visual perception, electroencephalography (EEG) studies show evidence for neural mechanisms underlying face processing. Humans show a characteristic event-related potential (ERP) associated with face stimuli at 170 milliseconds after stimulus exposure, called the N170 peak. Although there are other EEG signatures of faces, such as the P1 and N290, the N170 is most specific to faces, and is sensitive to inversion effects, whereby recognition of changes in upside-down faces is impaired due to holistic processing inferences (Roisson et al., 2000; Simion & Griorgio, 2015). The EEG and fMRI evidence for face perception as a distinct neurological mechanism is not present in humans until they reach at least three months of age, suggesting that while evolutionary pressures have shaped some of the underlying face processing circuitry, experience also plays a critical role (Itier & Taylor, 2004). Visual stimulation of faces throughout the critical period is also thought to shape the identified mechanisms for face processing.

Further, the neurological signatures of face processing are evident at the behavioral level. Eye-tracking studies reveal a triangular fixation pattern that cycles between the eyes and mouth when humans view faces (Figure 1). Alfred Yarbus, a Russian psychologist, pioneered eye-tracking studies with faces, using suctioned contact lenses, a method that was adopted by



Figure 1. Eye-tracking Heat Map Depicting Neuro-typical Gaze Behavior. Combined average fixation locations of 22 subjects. Warmer colors indicate more time spent fixating in those areas.

those who followed him in the field (Yarbus, 1967). Yarbus' work on a single subject yielded the key insight that there is a strong preference for looking at the eyes more than any other feature when viewing images that contain faces. The scanning patterns employed while viewing faces led to a general acceptance that face processing occurs holistically: integration of facial features occurs so that humans see faces as a whole, rather than a sum of their parts (Yarbus, 1967; Tatler et al., 2010; Andrews et al., 2010). Yarbus' work has since been replicated and extended to suggest that gaze behavior predicts attention to visual cues such as color, orientation and intensity (Itti et al., 1998). In other words, human eye movements are highly correlated with visual attention. In combination, these results suggest that humans fixate more on the eyes of faces and that this gaze behavior results from an increased attentional demand associated with social cognition.

II. Color Vision

Although extensive research exists surrounding face processing and gaze behavior, most studies use achromatic grayscale stimuli to study face processing because color is seen as a complicating or confounding factor for stimulus design, analysis, and interpretation. While the studies conducted with achromatic stimuli have reliably elicited responses in the face-selective cortical regions discussed above, color is an integral component of natural faces, and its role in facial processing has yet to be thoroughly investigated.

Color vision is thought to have existed in most vertebrates and invertebrates, with the degree of development varying by each species' needs. Birds likely have the most developed color vision system (Pichaud et al., 1999). Other than catarrhines (apes and humans), some female platyrrhines (new world primates), and some female strepsirrhines (lemurs), most mammals have a less developed, dichromatic, color vision system. Despite widespread

anatomical differences, there is a high degree of functional similarity in color vision across species (Pichaud et al., 1999).

Moreover, color vision appears to have evolved independently several times, before reaching its current trichromatic state in apes and humans. Trichromacy refers to the processing of three different channels of color information, which map to three different types of cone photoreceptors in the retina. Trichromacy was first observed in catarrhines, whose polymorphisms in opsin genes provided them with the ability to possess an additional dimension of contrast about 40 million years ago. Trichromacy was adaptive in allowing for primates to detect objects in foliage at a distance, perform image segmentation, and disambiguate shadows and shading from changes in surface reflectance (Johnson & Mullen, 2016). Thus, trichromatic color vision primarily aided primates in determining the location, shape, identity and characteristics of objects, and distinguishing objects when they are camouflaged or obscured (DeValois & Webster, 2011). These behaviors are particularly important in the context of foraging, where it is highly adaptive for animals to be able to discriminate color in searching for food. In humans, color vision remains important for navigating the environment. Humans suffering from color blindness face difficulties cooking and choosing food, driving cars, picking clothes and, when conditions are degraded, recognizing faces (National Eye Institute).

Broadly speaking, color vision begins by comparing the inputs to neurons in the retina from photoreceptors selective for different wavelengths. In trichromatic primates, including humans, there are three types of cone photoreceptors: short wavelength (S), medium wavelength (M), and long wavelength (L), so named because of their different spectral sensitivities across the visible spectrum (~390-700 nm). A subset of retinal ganglion cells receives opponent signals from different types of cones, thereby subtracting signals to aid in the differentiation of

wavelength from light intensity, providing information about color. A different subset receives signals from different cone types and sums these, rather than subtracting them. These neurons encode achromatic luminance contrast, not color contrast.

Historically, color perception was thought of as a discrete analysis process performed by the brain independently of other aspects of visual processing, such as form or orientation. This modular view of color perception was supported by the fact that neurons in different brain areas respond preferentially to different aspects of vision. The lateral geniculate nucleus of the thalamus (LGN) receives color inputs from the retina and relays them to the cortex. The middle temporal visual area (V5) is largely unresponsive to color but responsive to motion, while visual area 4 (V4) contains many neurons that guide attention, as well as those that respond preferentially to color, which led to the opinion that V4 was responsible for color perception. However, more recent evidence suggests that the primary visual cortex (V1) inextricably links color and form to account for the subjectivity of color perception (Shapley et al., 2014). Most of these V1 neurons are responsive to both color and luminance, suggesting that early visual processing integrates color into low-level visual processing mechanisms (Johnson et al., 2001). In support of this more integrated model, evidence shows that color and form reciprocally influence each other, suggesting that color signals carry spatial information and vice versa (Tanaka et al., 2001). In this way, color may not be a distinct modality, separate from other visual features, such as contour and shape, though it is likely separate from motion.

In addition to being integrated in visual perception, color contributes to high-level visual perception by providing top-down information in object recognition through color knowledge. Eye-tracking evidence supports the importance of the role color in visual perception, suggesting that color is a critical attribute of saliency. Jost et al. (2005) used saliency maps of images based

on color, orientation, and intensity. These maps represented predictions of fixations and attention based on those features. Saliency maps of color images more accurately predicted fixation behavior than did those of achromatic images, demonstrating that color contributes to visual attention (Itti et al., 1998). With objects, color has been shown to help us recognize objects faster and remember them longer (Gegenfurtner & Reiger, 2000). Thus, color can enhance the perception of visual stimuli by demanding increased attention and aiding in processing mechanisms. Given the high degree of saliency that both color and faces provide, it is likely that color influences face processing. In fact, three proposed color-biased cortical regions have recently been found to be sandwiched between face-selective and place-selective cortical regions, suggesting that this tripartite face/color/place system may be even more integrated than previously thought (Lafer-Sousa et al., 2016).

III. The Role of Color in Face Perception

Given the importance of color in visual perception, examining the specific effects of the role of color in face processing is warranted. Studies manipulating color suggest that there is no significant difference in recognition performance when faces are presented in color or grayscale conditions (Kemp et al., 1996). In replicating these results, Yip & Sinha (2002) proposed that the need for color information is diminished because luminance provides redundant information through segmentation. However, when conditions are degraded and other visual cues are less available, color contributes more significantly in facilitating low-level facial image analysis (Yip & Sinha, 2002). In addition to studies on the impact of color on facial recognition, other studies have examined the role of color in face detection, which may be considered a lower-level form of recognition. Color has been shown to combine with luminance information to allow for a better estimation of the boundaries, shapes and sizes of facial features (Bindemann & Burton,

2009). Further, Bindemann & Burton (2009) found that reaction times for identifying faces were faster for color versus grayscale faces. Facial color, such as redness, has also been shown to enhance perception of aggression, dominance, and attractiveness (Stephen et al., 2012), suggesting that color plays a role in emotion expression and perception.

Although behavioral studies have addressed the role of color in face detection and recognition, few studies have assessed how color might affect gaze patterns during face processing, as measured with eye-tracking. For my thesis project, I used eye-tracking to measure gaze patterns for both color and achromatic faces to understand whether color impacts the tendency of individuals to focus on the eyes of the face. Removing color cues from faces may cause neuro-typical individuals to spend more time fixating on the eyes, given that some socially relevant information provided by color is unavailable. Given that the eyes provide clues to decipher emotion (Baron-Cohen & Cross, 1992), achromatic stimuli might necessitate longer fixation on the eyes, suggesting that color plays a supportive role to typically employed face processing mechanisms. Results from my study in a neuro-typical population may also inform how color contributes to gaze behavior of faces in populations with and at-risk for social and developmental impairments and differences.

IV. The Role of Color in Face Processing in Autism Spectrum Disorders

Beyond the neuro-typical population, further understanding of the role of color in face processing can be extracted from evidence of disruptions, as are prevalent in individuals with Autism Spectrum Disorders (ASD). ASDs are developmental disorders associated with disruptions in non-verbal communication, social relationships and stereotyped patterns of behavior. Individuals with ASD typically display an aversion to eye contact, as well as persistent deficits in social communication and interaction (DSM-5). Individuals' gaze aversion may be

connected to their inability to recognize and interpret others' nonverbal emotions and expressions, either in a "top-down" causal or "bottom-up" resultant fashion (Lord et al., 2000). Understanding how deficits in face processing originate could lead to novel interventions in ASD treatment and prevention, while elucidating further insight into neuro-typical face processing mechanisms (Golarai et al., 2006).

While viewing faces, adults with ASD consistently tend to spend less time fixating on the eyes compared to neuro-typical controls. Additionally, the facial scanning pattern in ASD is more erratic and less triangular, with fixations unpredictably focusing on the ear, chin or hair. These differences have been shown to predict ASD symptoms and diagnosis (Klin et al., 2002; Golarai et al., 2006). In addition, while neuro-typical individuals view faces holistically, as described above, eye-tracking and behavioral evidence points to individuals with ASD processing faces elementally (Pelphrey et al., 2002). For example, individuals with ASD are better at identifying faces when presented with a feature of the face than typically developing individuals are (Joseph & Tanaka, 2003). Taken together, eye-tracking and behavioral evidence points to the employment of different face processing strategies in ASD populations. Eye-tracking behavioral studies thus provide a reliable basis for exploring face processing in individuals with ASD. Using eye-tracking in conjunction with color manipulations further elucidates differences observed in ASD populations. Most studies using color face stimuli find significant differences in fixation time spent viewing the eyes in neuro-typical and ASD populations (Wagner et al., 2013). However, studies using achromatic face stimuli have yielded conflicting results; some (e.g. McPartland et al., 2011) do not find the same divergence in gaze behavior between ASD and typically developing individuals, while others do (e.g. Klin et al., 2002; Dalton et al., 2013; Hernandez et al., 2009). Although there are other differences in

methodology that may contribute to the different results, color likely plays an important mediating role in face processing for ASD populations.

In addition to the disruption of typical gaze behavior, particularly with respect to fixation on the eyes, individuals with ASD show independent impairments in color perception. Franklin et al. (2008) demonstrated that children with ASD show significant impairments on two different color-related tasks: color memory and chromatic discrimination. They suggest that less accurate color perception could arise from various cultural or social factors or from biological differences present in ASD pathology and concurrent with visual processing. In contrast, O’Riordan et al., (2001) found that children with ASD performed better than typically developing children on visual search tasks where targets varied by small differences in color, suggesting those children exhibit hyper-acute color perception. Finally, Davis et al. (2006) found that individuals with ASD show dysfunction in parvocellular cells responsible for color vision; however, the difference may be understood as either an impairment or an overload, with divergent manifestations.

These accounts suggest that both face perception and color vision are affected in ASD, calling for the present study to assess differences in the perception of color and achromatic faces in an ASD population. Given that individuals with ASD focus less on the eyes of faces, and color provides important cues for face detection, one might expect that removing color from faces changes the degree of fixation on the eyes. Specifically, removing color may provide a less natural representation of the face that individuals with ASD may find less anxiety-inducing or more socially-rewarding, resulting in increased attention to the eyes. Further, if color aids in face detection, removing it could necessitate increased fixation on the eyes to compensate for the missing information.

My study incorporated the Broad Autism Phenotype Questionnaire (BAPQ) to assess how gaze behavior and color manipulations are affected by the presence of ASD-like behaviors and traits in a neuro-typical population. The BAPQ is a set of personality and language characteristics that reflect where healthy subjects fall on the ASD phenotype spectrum. The questionnaire was originally developed to understand the phenotypic expression of the genetic liability to ASD in relatives of individuals with ASD. The BAPQ assesses phenotype on subscales of aloofness, pragmatic language usage, and rigidity, and has been shown to have high levels of validity and internal consistency (Hurley, 2007). The BAPQ allows for an analysis of how color affects the ability of individuals to fixate on the eyes, as mediated by non-clinical ASD symptoms. Insights gained could contribute to a deeper understanding of social communication deficits that arise from differences in visual perception. Further, this information could inform both an understanding of the genetic basis and the neural etiology of the disorder. Subjects with higher BAPQ scores may fixate on the eyes of achromatic faces over faces presented in color even more so than subjects with lower BAPQ scores, because the removal of color may render the eyes both less socially informative and less aversive to individuals who have similar phenotypes to those with ASD. This would result in longer dwell times. My study is novel in combining color theory with eye-tracking technology during free-viewing of faces, with the aim of informing how color influences gaze behavior and face processing deficits observed in individuals with ASD phenotypes.

Methods

a. Participants

25 healthy subjects with normal or corrected-to-normal vision volunteered to participate in the behavioral aspect of this study. Six subjects were excluded from

subsequent analysis due to mis-calibration of the eye-tracker and technical malfunctions, and the results of the remaining 19 subjects (12 females, 7 males, mean age: 20.8 years) were included in analysis. The research protocol and informed consent forms were approved by the Duke University Institutional Review Board.

b. Experimental Design

Subjects were first administered The Kaufman Brief Intelligence Test (KBIT) to obtain a concise measure of verbal or crystallized intelligence and nonverbal intelligence or fluid reasoning (Kaufman & Kaufman, 2004). The test asks vocabulary questions to measure verbal knowledge, and matrices and riddle questions to measure innate intelligence (Figure 2). The KBIT is both brief and easy to use, making it a commonly used research tool in differentiating individuals with high functioning autism (HFA)

(Gray, 2013). Because our study evaluates behaviors associated with ASD, such as the tendency to maintain eye contact, the KBIT was included in the battery to understand where these healthy participants fall in cognitive functioning compared to individuals with HFA.

Next, subjects completed the eye-tracking task (described further below). Following the eye-tracking task, subjects performed the Social Intelligence Test (SIT), which measures how well one can read the emotions of others just by looking at images

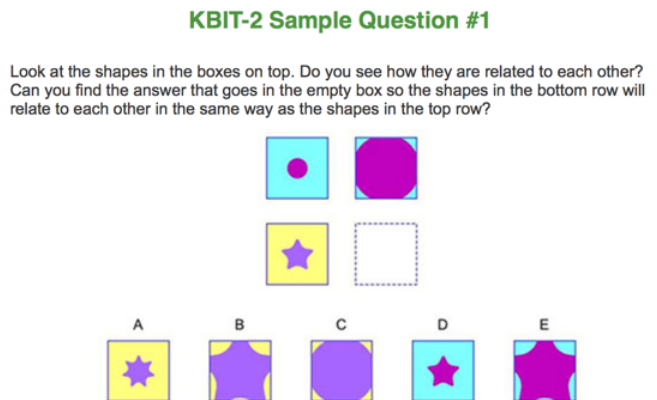


Figure 2. Sample KBIT Question. A matrices subtest question measuring fluid reasoning. (Source: testingmom.com)

of their eyes (Baron-Cohen et al., 2001). SIT scores have been shown to negatively correlate with the Autism Spectrum Quotient (AQ), a measure of ASD traits in normal adults, as well as individual differences in social sensitivity, making it relevant to the present study (Baron-Cohen et al., 2001).

Upon completion, subjects were directed to a website which instructed them to complete a survey including demographic questions and personality-based questions, aimed at accurately establishing a baseline for social competency and behavior. The 120-question Revised NEO Personality Inventory (NEO-PI-R) was used to determine personality based on individual classification within the “Big Five” dimensions of personality traits: extraversion, agreeableness, conscientiousness, neuroticism, and openness to experience (Johnson, 2014). This type of Big Five personality assessment has been used widely to predict various behaviors, including ASD symptom severity and how people view faces, making it relevant to the present study (Schwartzman, 2014; Perlman et al., 2009). Finally, the Broad Autism Phenotype Questionnaire (BAPQ) was administered through another online Qualtrics survey (Hurley et al., 2007). The BAPQ measures personality and language characteristics that reflect the phenotypic expression of genetic liability to ASD in non-autistic relatives of individuals with ASD.

Additionally, the BAPQ has been used in subjects without relation to individuals with ASD to assess phenotypic behaviors associated with ASD such as social motivation (Jobe & White, 2007). Of this battery assessing ASD-like behaviors and traits, the BAPQ was the measure on which the present study focused, and its analysis will be discussed further below.

c. Eye-Tracking Experimental Design

Eye-tracking data was collected using a Tobii T60 screen-based eye-tracking system (Tobii Technology, Stockholm, Sweden) with a high-resolution 24-inch monitor. The eye-tracking system is completely non-invasive, with no need to artificially constrain head or body movements. The eye tracker was interfaced and controlled using custom MATLAB scripts, created using the Psychophysics Toolbox extensions (Kleiner et al., 2007; Brainard, 1997). The eye tracker was calibrated for each participant using a 9-point calibration of each eye, whereby each participant followed the location of rotating geometric shapes appearing at unique locations around the screen (User Manual-Tobii Studio Version 3.2).

The experiment aimed to establish a baseline for typical facial analysis, mirroring the cyclic scanning behavior of the eyes, nose, and mouth demonstrated in previous research. To this end, a stimulus set of 105 images containing face and face-like images was presented to each subject. The categories of visual stimuli included high quality photographs of forward-facing and profile faces, of which sub-categories included blurred faces, color faces, grayscale faces, spatial frequency filtered faces, painted artistic portraits of human faces, more abstracted artistic renderings of faces, animal faces, still-life paintings and collages to provide stimuli of the same artistic style, but not containing face-like representations, and a series of everyday objects that incorporate configural properties of faces. Each of the categories was equally represented among the 105 stimuli, and of the representational faces, roughly half appeared in a front-facing view and the other half appeared in a side profile view. Non-representational stimuli in the set were included in other, concurrent studies; however, they were excluded for the present

analysis. Each trial began with a fixation cross appearing at a random location (restricted to a region centered in the middle of the screen and comprising 66% of the screen width and height) on the screen. This was done to remove the potential biasing effect of start position on the resulting fixation pattern (Arizpe et al., 2012). Subjects were instructed to attend to the fixation cross, and

indicate their readiness to begin the next phase of the trial with a key press. After the key press, an image appeared on the screen for 5 seconds, during which the subjects are asked to “view the image as naturally as possible.” Subjects received a short

break after every 30 trials. The average eye-tracking session time was 17.1 minutes (Figure 3).

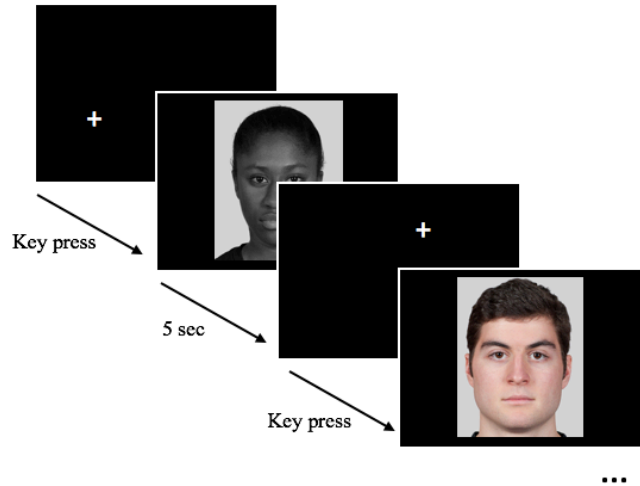


Figure 3. Eye-tracking Task Flow. The location of the fixation cross was randomized. Following a key press, each of the 105 face images appeared on the screen for 5 seconds.

d. Analysis

Eye-tracking data analysis

The Tobii eye tracking system collects data on gaze location expressed in screen coordinates. Using a custom web-based Javascript application, four student investigators drew areas of interest (AOI's) covering each eye, nose, and mouth, for each of the 100 stimuli containing any face-like representation. All student investigators were familiar with the task and the goals of the study and abided by drawing instructions that included covering the orbital socket for each eye, following the contour halfway up the bridge of

the nose and full coverage of the lips with a border. The final AOI for each region on each image was determined by overlaying each of the four investigators' drawings, and selecting all pixels that were included by at least two investigators. Overlapping AOIs within the same image were masked to ensure that every pixel could be assigned to one and only one AOI.

Examples of AOIs are shown in Figure 4.

The raw data were filtered to fill in missing data points attributable to blinks, or short gaps in pupil detection. The filtered data was then used to define fixations for each trial. Dispersion-based thresholding was used with a fixation duration threshold of 100 milliseconds and a dispersion threshold of 1.5 degrees of

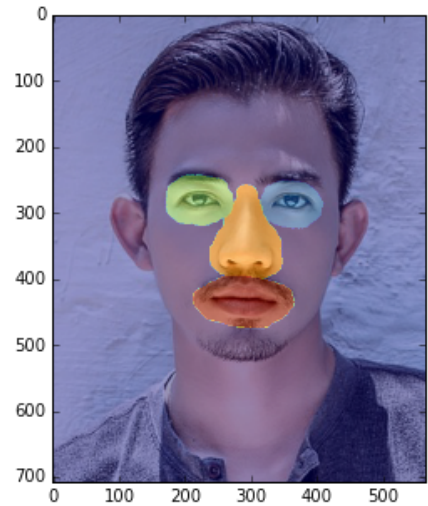


Figure 4. Example of AOI's drawn to corresponding face stimulus.

visual angle to determine when fixations occurred (Salvucci & Goldberg, 2000). Next, fixations within a trial were summarized for each subject by averaging the x, y locations of all gaze points belonging to that fixation. The fixation location was then compared to the AOI regions to determine whether a fixation fell within an AOI. The duration of each fixation was also determined.

Given the defined fixations, all fixations within a single trial were summarized for each subject to calculate the proportion of time subjects spent fixating on each AOI in contrast to their non-fixation periods. The AOI categories were the following: left eye, right eye, nose, mouth, and other. The "other" category included any fixations that did not fall in one of the above AOIs. For this analysis, we extracted the combined fixation time spent on both eyes as a proportion of the trial time as the measure for dwell time on

the eyes for all trials corresponding to a subset of 22 images that included normalized photographs of faces in a front-facing orientation. Of these images, 12 were unaltered and presented in color, while 10 were presented in grayscale. Given that there was no effect across right and left eyes upon initial analysis, combined dwell time on both eyes was the primary AOI used to identify fixation on the eyes (Cangialosi, 2016). The proportion of dwell time on the eyes was summarized for these relevant trials to obtain an overall measure of proportion of the trial time spent fixating on the eyes of the images for all 19 subjects. For more information

see: https://github.com/jeffmacinnes/AVB_tobii_pipeline/blob/master/filteringSteps.ipynb

BAPQ Analysis

The BAPQ administered consisted of 36 statements scored on a Likert scale of 1-very rarely applies to me to 6-very often applies to me (Appendix A). Subjects were instructed to think about the way they are with most people, rather than the way they are in special relationships with family or significant others. They were also instructed to answer questions according to how they have been the majority of their lives, as opposed to how they may have been at a particular stage or time in their life. Of the 36 questions, 12 fell in each of the 3 subscales: aloof, pragmatic language, and rigid. Scores were summed for each of the subscales based on reverse scoring for some of the items. Based on prior literature, sums were then averaged within each category to obtain an average score on each subscale, then those averages were averaged across subscales to obtain a total average score for each subject that fell between 1 and 6.

Statistical Analysis

Statistical analyses were performed in R Studio. Descriptive statistics were generated for subjects' dwell time on the eyes as a proportion of the trial time (5 seconds) for grayscale and color images. Next, a paired-samples t-test was conducted to determine if subjects' mean dwell time on the eyes differed significantly between grayscale and color images. To investigate potential relationships between color manipulations and ASD phenotypes, I conducted exploratory analyses correlating BAPQ scores to the degree to which subjects fixated *more* on the eyes of grayscale. Based on the best-estimate cutoffs published in the literature and the sample size of the population, a cutoff score of 3.00 was used to split subjects into high and low BAPQ populations (Hurley et al., 2007). These subgroup scores were then separately correlated with the difference scores (fixation time on eyes of grayscale faces > color faces) to determine whether effects might be specific to subjects with high BAPQ scores only. Linear regressions were also performed on all correlations conducted to determine statistical significance.

Results

Participants in this study spent more time on average fixating on the eyes of faces presented in grayscale compared to time spent fixating on the eyes of face stimuli presented in color (Table 1). The paired-samples t-test revealed a significant positive difference in the mean proportion of the trial time spent fixating on the eyes for grayscale faces over color faces, ($t(18) = 2.77, p < 0.05$) (Figure 5). Subjects spent an average of 20%, of the trial (1.0 second) fixating on the eyes when viewing color face stimuli. While viewing grayscale images, they spent an average of 24% of the trial (1.2 seconds) fixating on the eyes.

BAPQ scores in this sample fell within the average range (2.55-2.98) of those without a relative with ASD (Hurley et al., 2007; Sasson et al., 2013; Feldman, 2015). The total mean score across subjects in the current study ($n = 19$) was 2.89 ($SD = \pm 0.49$). The breakdown of scores across subscales is shown in Table 2. This distribution of the average score across subscales is consistent with reported values, where scores for *rigid* are greater than *aloof* scores, which are greater than *pragmatic language* scores (Hurley et al., 2007; Sasson et al., 2013; Feldman, 2015). The large variance is likely explained by the small sample size.

Subsequent analyses explored how subjects' BAPQ scores may predict their tendency to focus on the eyes of grayscale and color images. These analyses revealed a moderate correlation across our sample between BAPQ score and the difference in proportion of trial time spent viewing the eyes of grayscale compared to color faces ($r(17) = 0.28, p = 0.25$) (Figure 6). This correlation did not reach statistical significance. However, the association suggests that the participants with higher BAPQ scores spend more time focused on the eyes of grayscale face images than color face images than the participants with lower BAPQ scores.

Post-hoc exploratory analyses involved splitting the BAPQ scores at 3 based on reported cutoff measures and sample size, to obtain high ($BAPQ \geq 3, n = 6$) and low ($BAPQ < 3, n = 13$) scoring groups. Performing correlations with these two groups separately revealed a stronger correlation between BAPQ score and the difference in time spent fixating on the eyes of grayscale faces and color faces ($r(4) = 0.36, p = 0.49$) for the high BAPQ group (Figure 7). Further, the subjects with BAPQ scores less than 3 showed little correlation with the tendency to focus more on grayscale face over color faces ($r(11) = 0.09, p = 0.77$) (Figure 8). These results suggest that the high BAPQ subgroup in our sample drove most of the correlation when the two groups were combined. Tending to score higher on the BAPQ, an autism phenotypical behavior

assessment, may be associated with longer dwell times on the eyes when images of faces are presented in grayscale. A summary of the BAPQ score breakdown is shown in Table 3.

Table 1

Dwell Time on the Eyes of Color and Grayscale Faces

	<u>Proportion of Trial Spent Fixating on the Eyes</u>	<u>Standard Deviation</u>	<u>Standard Error</u>
Color Faces	0.20	0.13	0.03
Grayscale Faces	0.24	0.13	0.03

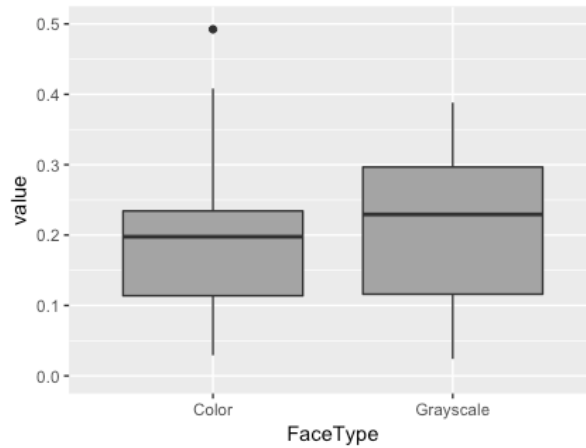


Figure 5. Proportion of Trial Time Spent Fixating on the Eyes by Image Type. Time spent viewing the eyes of grayscale face images (24% of trial, 1.2 seconds, $n = 10$ images) significantly longer than that for color face images (20% of trial, 1.0 seconds, $n = 12$ images) ($t(18) = 2.77, p < 0.05$).

Table 2
Subjects' Average BAPQ Scores

	<u>Mean</u>	<u>Standard Deviation</u>	<u>Official Cutoff (Hurley et al., 2007)</u>
Aloof	2.87	0.49	2.87
Pragmatic Language	2.72	0.52	2.75
Rigid	3.05	0.70	3.50
Total Score	2.89	0.49	3.15

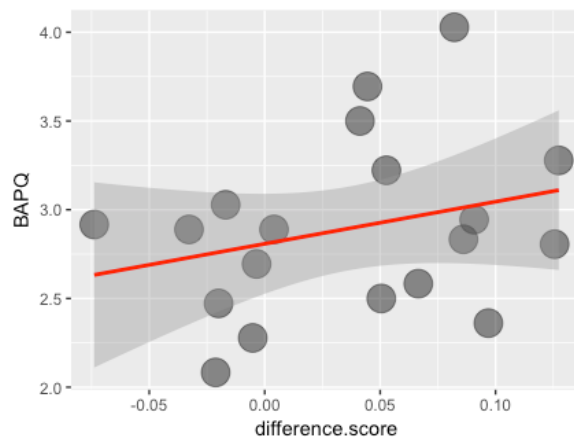


Figure 6. Correlation between BAPQ Scores and Time Spent Viewing Eyes of Grayscale Face Images over Color Face Images. ($r(17) = 0.28, p = 0.25$)

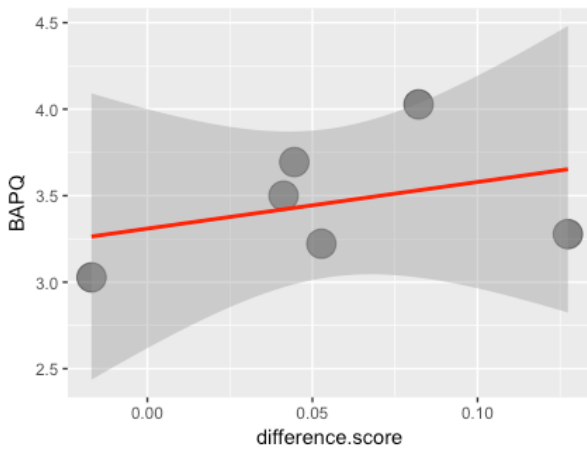


Figure 7. Correlation between High BAPQ Scores and Time Spent Viewing Eyes of Grayscale Face Images over Color Face Images. ($r(4) = 0.36, p = 0.49$) (n = 6)

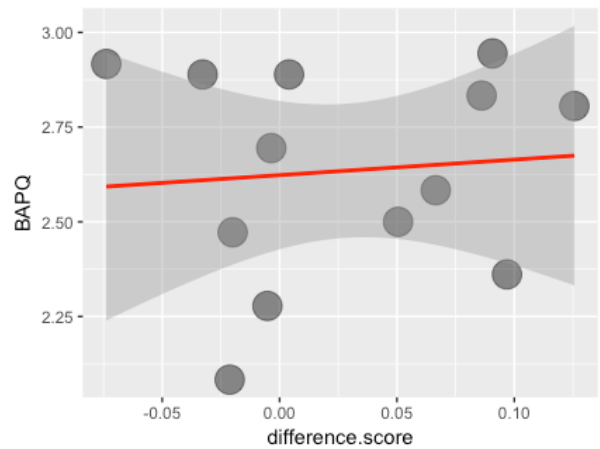


Figure 8. Correlation between Low BAPQ Scores and Time Spent Viewing Eyes of Grayscale Face Images over Color Face Images. ($r(11) = 0.09, p = 0.77$) (n = 13)

Discussion

The results suggest that removing color from images of faces leads to longer dwell times on the eyes of those images compared to unaltered, color images of faces. There could be many potential reasons for the significant difference in dwell time on the eyes, but perhaps, the difference is because grayscale images hold less social information due to their lack of color cues. Color-cued social information may aid in emotion perception (Stephen et al., 2012). Because the eyes are considered to be rich in socially relevant information, removing color would decrease the information necessary to perform functions associated with emotion detection and recognition, causing a need to spend more time viewing the eyes. If color were only providing visual salience information, and not social information, the gaze behavior may also change. For example, the areas of contrast may demand more attention, due to absence of other, color-driven, attentional demands (Jost et al., 2005). However, the increase in dwell time specifically on the eyes suggests that the role color plays is connected to social acumen, rather than generalized visual deficits, although further exploration into the dwell times of other AOIs is necessary. One limitation of this theory is that the study was conducted with “neutral” faces (faces lacking overt emotional expression); however, neutral expressions still cause viewers to have emotional reactions, encouraging expression discrimination (Lee et al., 2008).

The distribution of scores on the BAPQ is consistent with what is expected for a control population (Hurley et al., 2007; Sasson et al., 2013; Feldman, 2015). Although the correlation was insignificant, the individual differences in BAPQ scores did predict the proportion of time that subjects focused on the eyes of grayscale face images over color face images within 5 second viewing trials. Exploratory post-hoc analyses revealed that the correlation was driven primarily by the high BAPQ scores (greater than 3). This result suggests that the phenotypic

abnormalities present in ASD may affect the relationship between color and eye fixation behavior, further necessitating follow-up studies in ASD-diagnosed populations. The association, albeit insignificant, between BAPQ scores and the difference in time spent fixating on the eyes when faces were presented in grayscale rather than color, further suggests that social motivation factors are implicated in the color manipulation. In sum, the significant difference in fixation on the eyes of grayscale faces over color faces suggests that color provides cues critical to social communication, especially given the small sample size.

Furthermore, because social communication deficits are a primary indicator of ASD, future studies exploring the effects of color on eye contact in a clinical population are imperative in understanding the disorder's etiology. Social communication deficits in ASD are thought to be driven by either a hyperactive anxiety response to socially salient stimuli or by a hypoactive reward signal from socially salient stimuli (Kleinhans et al., 2010; Chevallier et al., 2012). The latter suggests that social communication deficits can be ameliorated through reward conditioning, if implemented early. If grayscale faces appear less complex or aversive, individuals with ASD may fixate more on the eyes of them in comparison to color faces. However, if individuals with ASD do not see faces as social stimuli, the effect of removing social information through color may not alter their gaze behavior or they may look more at the eyes of color faces over grayscale faces because they are more detailed and interesting. Examining how color manipulations in faces relate to symptom severity in a clinical ASD population, rather than in relation to the BAPQ metric, will help to clarify some of these outstanding questions concerning ASD. Understanding the association between symptom severity and the tendency to fixate on the eyes of grayscale faces compared to those of color

faces could lead to improvements in behavioral therapies, which condition individuals with ASD to maintain eye contact through social reward (Dawson et al., 2010).

Finally, the results of this study suggest that the field must increase the use of chromatic stimuli in eye-tracking studies, given that color seems to be not only a confounding factor for analysis but also a critical element in visual and emotion perception. This implication is particularly relevant to behavioral paradigms such as the Reading the Mind in the Eyes test,

developed by Baron-Cohen et al. (1997), which uses achromatic stimuli to gauge social intelligence (Figure 9). The results of my study suggest that using achromatic stimuli in this task, and those similar, likely detracts from the ability of neuro-typical, and even more so, ASD individuals, to discern emotion. Future studies must therefore include chromatic stimuli to ensure that gaze behavior is simulated naturally, though the use of grayscale stimuli may require greater effort with respect to social cognition.

Other future directions include analyzing the effects of more color manipulations, such as hue reversals or saturation, to understand whether only lack of color generates increased eye contact or if other unnatural color manipulations generate similar effects on gaze behavior. Expressive stimuli might also be used to understand how the presence of emotion influences gaze behavior when color is manipulated. Additionally, other measures, such as the order of fixations during the trial or number of cycles between the eyes, could be used to assess differences in gaze behavior. The total number of distinct fixations could also be extracted;

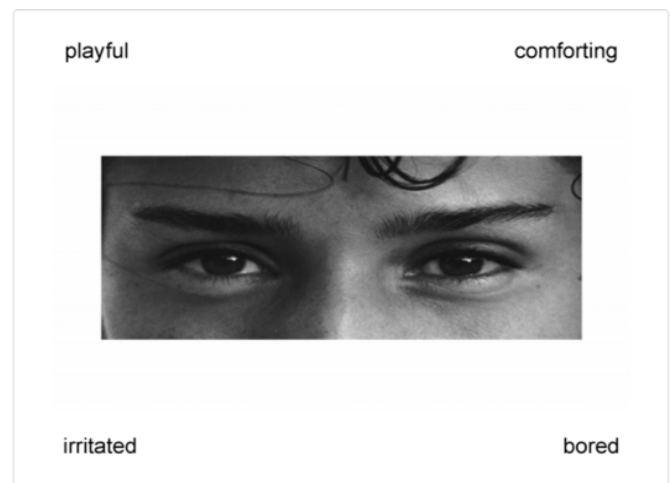


Figure 9. Sample SIT Item. Subject would be instructed to select the emotion portrayed in the eyes pictured.

however, using dispersion-based thresholding, fixations could vary in duration if they are above 100 milliseconds, thus overall dwell time on the eyes provides a more accurate measure of attention. These findings suggest that color provides critical social information associated with phenotypic ASD deficits, requiring further investigation into the role of color in face perception in ASD populations.

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Appendix A: Broad Autism Phenotype Questionnaire

1 - very rarely 2 - rarely 3 - occasionally 4 - somewhat often 5 - often 6 - very often

1. I like being around other people.
2. I find it hard to get my words out smoothly.
3. I am comfortable with unexpected changes in plans.
4. It's hard for me to avoid getting sidetracked in conversation.
5. I would rather talk to people to get information than to socialize.
6. People have to talk me into trying something new.
7. I am "in-tune" with the other person during conversation.
8. I have to warm myself up to the idea of visiting an unfamiliar place.
9. I enjoy being in social situations.
10. My voice has a flat or monotone sound to it.
11. I feel disconnected or "out of sync" in conversations with others.
12. People find it easy to approach me.
13. I feel a strong need for sameness from day to day.
14. People ask me to repeat things I've said because they don't understand.
15. I am flexible about how things should be done.
16. I look forward to situations where I can meet new people.
17. I have been told that I talk too much about certain topics.
18. When I make conversation it is just to be polite.
19. I look forward to trying new things.
20. I speak too loudly or softly.
21. I can tell when someone is not interested in what I am saying.
22. I have a hard time dealing with changes in my routine.
23. I am good at making small talk.
24. I act very set in my ways.
25. I feel like I am really connecting with other people.
26. People get frustrated by my unwillingness to bend.
27. Conversation bores me.
28. I am warm and friendly in my interactions with others.
29. I leave long pauses in conversation.
30. I alter my daily routine by trying something different.
31. I prefer to be alone rather than with others.
32. I lose track of my original point when talking to people.
33. I like to closely follow a routine while working.
34. I can tell when it is time to change topics in conversation.
35. I keep doing things the way I know, even if another way might be better.
36. I enjoy chatting with people.