DYSLEXIA AND COLOR PERCEPTION

Sandra Stark
Principal CEO at Stark-Griffin Dyslexia Academy
Johannesburg Area, South Africa 96

Abstract

Background: Acuity and accommodation result from a matrix response of the L (red), M (green), and S (blue) cone photoreceptors and the relative refractive focal depths of those specific colors. A Dyop® (or dynamic optotype) is a spinning segmented ring visual target which uses the strobic detection of the spinning gaps/segments of the ring to measure visual function. Dyop gap/segment color/contrast permutations have distinctive, and corresponding, acuity endpoints.

Methods: One hundred and eighty-eight patients, ranging from 4 years to 44 years in age, were examined as part of **Stark-Griffin Dyslexia Academy** to compare their color/contrast acuity endpoint perception of a spinning **Green-on-White Dyop** versus a spinning **Blue-on-Black Dyop** and the possible diagnosis of types of dyslexia. The patients were presented, as part of the Chart2020 vision test platform, a display which has an identical diameter spinning **Green-on-White Dyop** and spinning **Blue-on-Black Dyop** with sufficient arc width diameter such that both Dyop rings were detected as spinning. Those Dyop rings were then identically reduced in arc width diameter until spinning of each of the identical diameter colored rings was not detected. The smallest diameter ring where spinning was detected for each of the color/contrast combinations (corresponding to the acuity endpoint metric value) was recorded as its color acuity endpoint.

Results: Of the 188 patients, 166 (88% of the total) were formally diagnosed with dyslexia, and 22 patients **(12% of the total)** were diagnosed as **not** having dyslexia. Of the166 patients diagnosed with dyslexia, 151patients (86% of that group) detected the spinning **Blue-on-Black Dyop** while 9 patients (5% of that group) preferentially detected the spinning **Green-on-White Dyop**. Of the 22 patients **(12% of the total)** diagnosed as **not** having dyslexia, 12 patients (55% of that group) preferentially detected the spinning **Green-on-White Dyop** while 9 patients (41% of that group) detected the spinning **Blue-on-Black Dyop**. Of the 22 patients diagnosed as NOT having dyslexia, one was diagnosed as a "cognitively challenged," one was diagnosed as a "slow reader" (albeit NOT dyslexic) and one was diagnosed as having ADHD. There was an additional group of 16 patients (9% of the total) where there was no **Green-on-White Dyop** versus **Blue-on-Black Dyop** preference. Of the group with no color preference, 1 patient (5% of that group) was diagnosed as not having dyslexia, and 15 patients (95% of that group) were diagnosed with dyslexia. Of the 151 patients with a definitive color response and diagnosed dyslexia, 142 (94%) had a preferential detection of the spinning Blue-on-Black Dyop. Of the 21 patients with a definitive color response and diagnosed as not having dyslexia, 12 (57%) preferentially detect the spinning Green-on-White Dyop. While this is only a preliminary study, the association of the preferential detection of the spinning Blue-on-Black Dyop with the 94% association with diagnosed dyslexia definitely deserves further evaluation.

Conclusions: This is a preliminary evaluation of the disparity of color perception versus diagnosed symptoms of dyslexia. There was a very strong positive correlation ($r \leq 0.9$) between color perception and diagnosed symptoms of dyslexia. The findings suggest that symptoms presented by dyslexics could be better understood or analyzed by their color perception.

Keywords: Color perception, Visual acuity, Dyslexia, Dyop acuity chart.

Introduction

Numerous research projects have attempted to correlate color perception and symptoms of dyslexia, as well as symptoms of migraines and epilepsy. Many of those approaches, such as that of Wilkins[1], have used colored overlays to tint the apparent text background and hopefully increase legibility and cognition. Others have discovered that a tinted contact lens creates a more thorough response as to the visual field.[2]

Current acuity standards are based upon the relative cognition of European-style letters, as developed and copyrighted by 1862 Dr. Herman Snellen, which provide a visual target to assess acuity and refractive error.[3] The Snellen chart typically consists of multiple rows of letters as viewed at a testing distance of 6 meters (20 feet) in order for each letter on the 6/6 (20/20) Snellen visual acuity line to subtend a visual angle of 5 minutes of arc. The letters are typically larger at the top of the chart, and gradually decrease in size for each row as the patient continues to read down the chart.

The usages of the English alphabet and fonts have the advantage of being almost universally recognized within Europe and being relatively simple to administer. Since Snellen optotypes are no longer in copyright they also have the advantage that eye care professionals and optotype vendors can use the display of those letters with virtually no, or minimal, added expense. Printed paper charts, projected charts, and computerized versions of the Snellen chart are available. Printed paper charts or projected charts, however, have the disadvantage of being easily memorized, as clinicians are unable to present the letters in a random order.[4]

With the advancement of technology over the past few decades, computerized visual acuity chart systems have become popular among clinicians as they allow for a larger visual acuity range to be tested, allow for smaller incremental line displays, single or multiple target presentations, and the use of a variety of optotypes: Snellen-type letters, ETDRS charts (logMAR), Landolt C's (or rings), tumbling E's, numbers, children's symbols (Allen figures), HOTV charts, or LEA symbols.

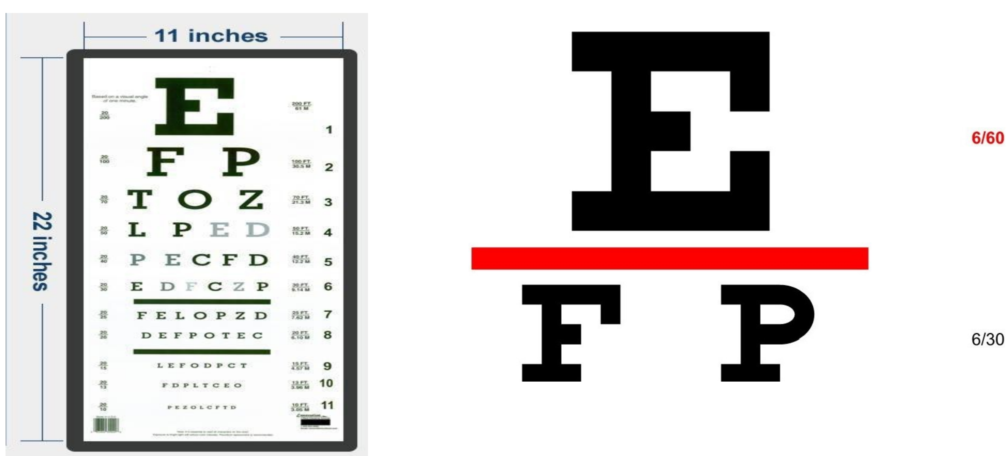


Figure 1: A Manual Snellen Acuity Chart, Source; National Eye Institute, National Institutes of Health and a Computerized Snellen acuity chart, Source; Chart2020® Version 10.3.6.

The disadvantage of letter-based recognition acuity tests is that cultures with a pictographic literacy preference find that the requirement for testing letter-based literacy is an impediment. The recognition acuity of letter-based tests is also an impediment for infants and non-literate individuals, letter-based tests are inherently imprecise due to the inconsistency of the visual stimulus areas, testing using only black optotypes on a white background ignores the fact that acuity is a function of color perception by the red and green and blue photoreceptors, letter-based testing ignores the biology that the ratio of red and green and blue photoreceptors is not uniform among humans, and that testing with static optotypes ignores the potential of image fixation which might possibly lead to a refraction overminus.[5]

In 2008 Allan Hytowitz discovered that a uniformly segmented spinning ring could provide a strobic visual stimulus as an optotype which uses resolution acuity. That binary strobic dynamic optotype, subsequently named a Dyop, has distinctive properties in that the combination of variables such as ring diameter (angular arc width), gap/segment stroke width, rotation speed (rotations per minute), gap/segment contrast, and gap/segment colors, combine to create a the strobic pixelized refresh rate of the photoreceptors as an indicator for visual acuity and other functional parameters for determining refractions.[6]

Because the Dyop acuity and refractive measurements are not dependent upon cultural cognition of letters, a Dyop test could also be used for infants, illiterate, and non-verbal individuals as a more accurate methodology for measuring acuity. Unlike static optotypes which get increasingly blurry as they get smaller or further away, detection of a spinning/rotating Dyop has a significantly sharper threshold as to the acuity endpoint based upon the angular arc width and viewing distance. The typical circular Dyop segmented ring is comprised of 8 black and 8 white equally sized alternating segments on a neutral gray background, spinning at 40 rotations per minute, and with a 10% gap/segment stroke width.[7] Since photoreceptors require a change in stimulus to evoke an excitatory response, a kinetic optotype such as a Dyop may more favorably match the visual response mechanism than static optotypes which use small eye motions (saccades) to help refresh the photoreceptors.

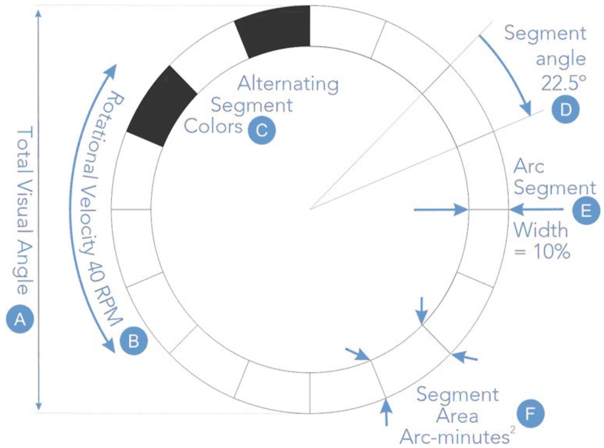


Figure 2: This illustrates the fundamental features of the Dyop (dynamic optotype) acuity chart. The total circular diameter or visual angle (A), speed of rotation (B), contrasting colors in black and white (C), segment angle (D), segment arc width (E), and area of each segment in minutes squared of arc (F).[7]

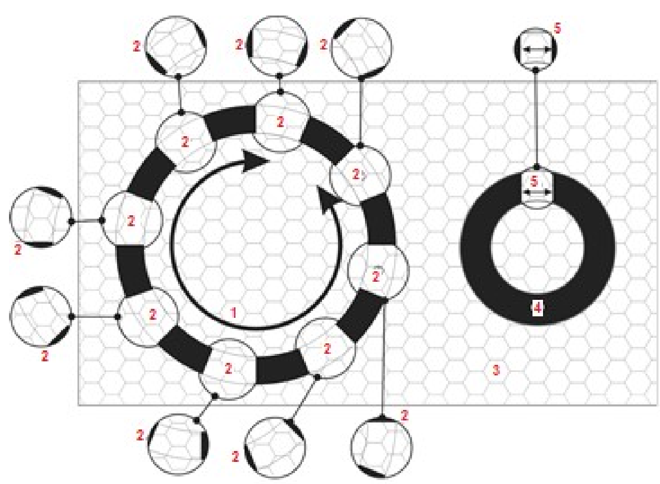


Figure 3: Display of the moving segmented areas of a Dyop and the resultant moving, stimulated individual areas superimposed on the retina.[7]

Item 1 – visual angular velocity or strobic contrast response
Item 2 – a moving segment visual arc-area dynamically stimulating retina cells with motion
Item 3 – retinal cells
Item 4 – an example of a static historical optotype
Item 5 – a static minimum angle of resolution of a historical optotype

VISUAL STIMULUS COMPARISON

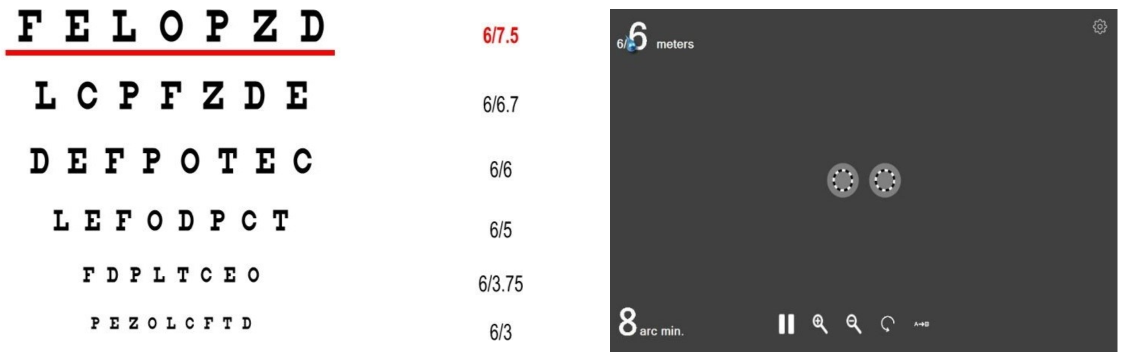


Figure 4: Comparison of Snellen and Dyop acuity chart. Source; Chart2020® Version 10.3.6 Computerized Visual Acuity Unit.

Harris and Keim[8] investigated the accuracy of Dyop acuity test with 162 participants by assessing the threshold acuities on a fully randomized basis, using Sloan letters and Dyop doublet with test conditions: uncorrected refraction and corrected refraction with +2.00 lens; +3.00 lens; +4.00 lens. There was a very strong linear Pearson correlation between Sloan and Dyop acuity measures, with all the test conditions for the subjects (Pearson $r = 0.95$; $p < 0.001$). The statistical variance in visual acuity measurement with the study condition revealed 0.193 and 0.035 for a projected Sloan and a Dyop doublet respectively.

The Dyop was reported to be advantageous due to the speed at which the threshold acuity endpoint is defined, simplicity of use, its finer acuity granularity as compared to the typical acuity "line" steps, ease of endpoint identification by the subjects, and ease of eliminating unreliable responses.

The optimal Dyop parameters for acuity/refraction measurement have a 10% stroke width (5% of the radius), a rotational speed of 40 revolutions per minute, and contrasting black/white gaps/segments on a gray background. With increases in blur, the Dyop response also has linear increase of the optotype angular width diameter versus the classic logarithmic Snellen increase.

That optimal Dyop also has an empirically determined 6/6 (20/20) Minimum AREA of Resolution (MAR) stimulus area of 0.54 arc minutes squared versus the averaged Snellen gap stimulus (MAR) of 1.00 arc minutes squared. That linear-Dyop versus logarithmic-Snellen disparity correlates to the Snellen gap having twice the area of the empirically measured Dyop gap. That MAR disparity likely also contributes to the higher variance of the Snellen acuity test versus a Dyop acuity test.

Dyop acuity testing is typically six times as precise as the Snellen test, with one-sixth the variance, and with twice the efficiency. The basic **Black/White-on-Gray Dyop** contrast maximizes the photoreceptor stimulus and minimizes the effect of ambient light on acuity measurement. The strobic photoreceptor stimulus of the spinning Dyop gap/segments matches the typical photoreceptor refresh rate, thus minimizing the effect of photoreceptor depletion.

The comparative guess rate may also influence the efficiency of the tests where there is a known choice of two possibilities for Dyop acuity chart (clockwise or counter-clockwise) while there are essentially 26 possibilities of the letter targets as the subjects are unaware of the limited selection of letters.

COLOR ACCOMMODATION

Acuity is a learned process resulting from the stimulus matrix of the retina red, green, and blue photoreceptors. Changing the color/contrast of a Dyop produces changes in the acuity endpoint response which reflects the relative ratio and focal depth response of red, green, and blue photoreceptors[9].

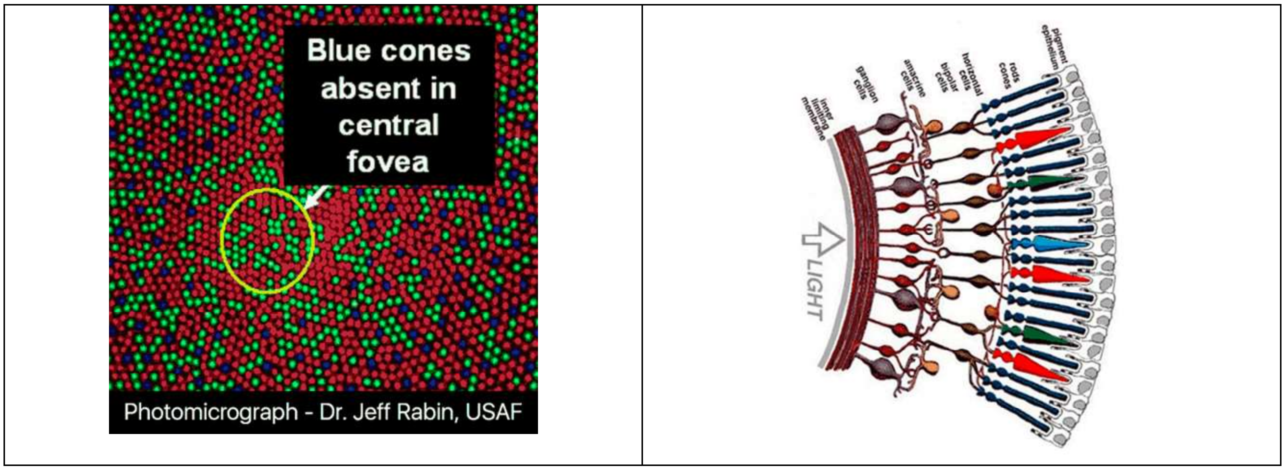


Figure 5: Fovea photomicrograph and illustration of the retina photoreceptor cones.

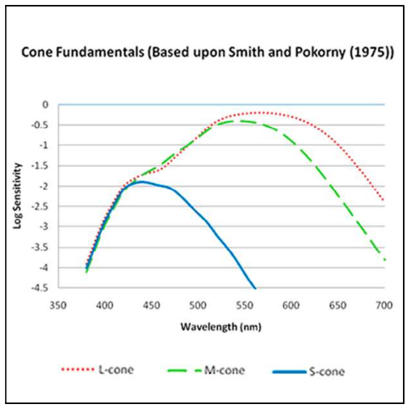


Figure 6: Photoreceptor sensitivity to the range of light by the retina cones.

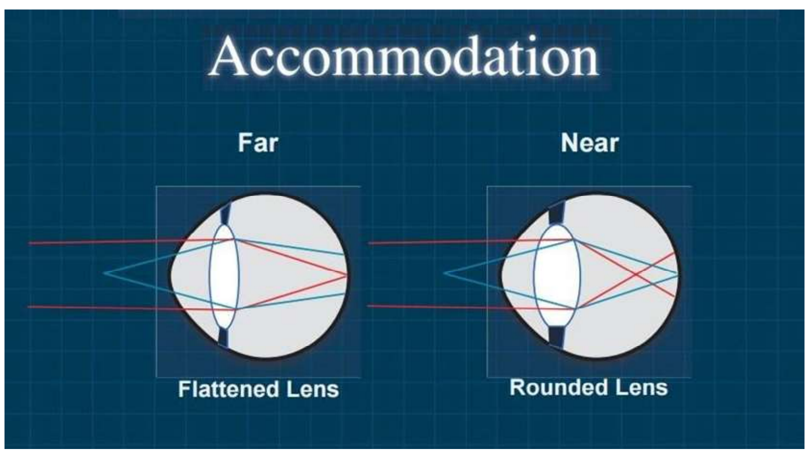


Figure 7: Accommodation as produced by the shape adjustment of the lens[10].

TYPES OF DYSLEXIA

Dyslexia seems to have little to do with intelligence, or limited intelligence[11]. Instead, it is primarily a reduced ability to read letter-based words which may be caused by visual stress. Rather than “letter reversal” the symptoms of dyslexia are the unstable letter images which impede decoding words from the combinations of letters.[12] The decoding difficulty creates the behavior of a slow reader. Ironically, one of the skills sometimes developed to reduce the difficulties of dyslexia is learning to read words as pictographs.[13]

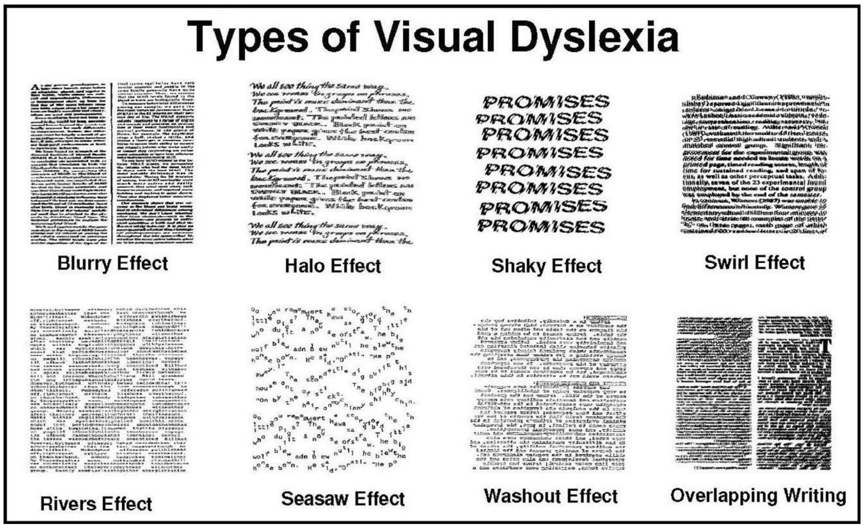


Figure 8: Representation of the visual instability associated with dyslexia.

Diagnostic Categories of Dyslexia

Code	Types of Dyslexia	Symptom	Combinations
1	Dysnemkinesia	Motor skills	
2	Dysphonesia	Auditory	
3	Dyseidesia	Visual	
4	Dysphoneidesia	Auditory & Visual	combination of 2+3;
5	Dysnemkinphonesia	Motor & Auditory	combination of 1+2;
6	Dysnemkineidesia	Motor & Visual	combination of 1+3
7	Dysnemkinphoneidesia	Motor & Auditory & Visual	combination of 1+2+3
8	Dysnomia	Name retrieval	
9	Double Deficit	Auditory & Name retrieval	combination of 2+8
10	Dyscalculia	Math difficulty	

Table 1: Diagnostic categories of dyslexia [14]

L/M RATIO DISPARITY

In 2007 Dr. Chris Chase of Western University in Pomona CA published his study that correlated the L/M ratio of photoreceptors to reading fluency in children[9]. What he discovered was that there were two population groups as to L/M ratios – a group with a higher red ratio with 75% red (L) and 20% green (M) and a group with a more balanced ratio with 50% red (L) and 45% green (M). (The other 5% in both groups were the blue photoreceptors.)

The disparity between these vision-related genetic groups is that the higher red ratio group (what we call "Red Focused Vision") has a more stable image for distance vision while the more balanced ratio group (what we call "Green Focused Vision") has a more stable image for near vision[10]. The advantage of Red Focused Vision is that it facilitates a more stable distance image for spotting predators, game, and using pictographs. Green Focused Vision has the advantage of a more stable near image for facilitating scientific discovery, reading letter-based words. As Dr. Chase discovered, the reduced near image stability of Red Focused Vision also contributes to being a "slow reader." We believe it also contributes to dyslexia and acts as a catalyst for symptoms of migraines and epilepsy.

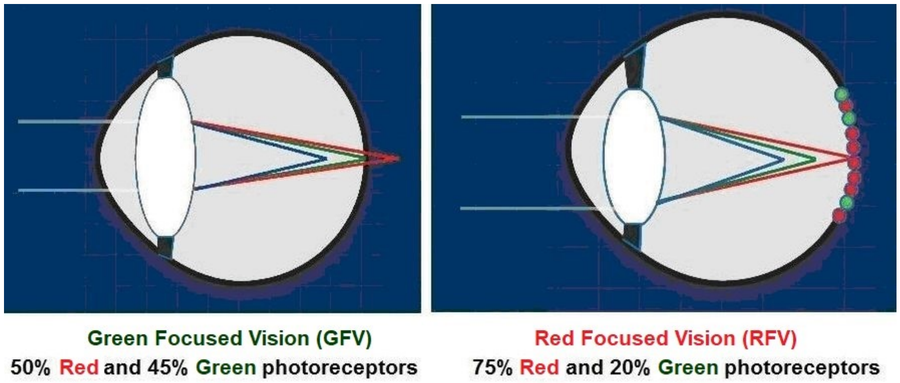


Figure 9: Difference in visual stress and accommodation due to the disparity in the red/green photoreceptor ratio[10].

In 2015 Drs. Christina Esposito and Paul Harris published their results in using a tinted contact lens to provide therapy for a patient with migraines[2]. They performed color sensitivity testing using an Intuitive Colorimeter (Cerium Optical Products). This logically and sequentially explored color space and helped to find the optimal precision tint for the relief of perceptual distortions, or in this case, migraines. They discovered as to the three parameters of color: hue, saturation, and brightness that while tinted glasses provided some migraine relief, using those tints for chromatic modulation with a contact lens provided a more thorough tint of the entire visual field and better therapeutic relief. It indicated that one of the difficulties in using tinted overlays for dyslexia relieve is that the overlays only tint the letters in the specific visual target rather than the entire visual field.

And despite the literature associating dyslexia with changes in the functioning of the brain[15], a recent study by Dr. Guinevere Eden suggests that "there is a general decrease in GMV (Gray Matter Volume) in the brain, suggesting an experience-dependent change in the opposite direction of age-specific changes"[16]. It is possible that the developmental visual stress and instability of Red Focused Vision might significantly contribute to the development of the cerebral disparities associated with dyslexia, rather than the associated cerebral disparities being causal.

DYOP COLOR PERMUTATIONS

The prototype 2010 Dyop color experimentation included an expanded matrix of 60 color permutations. (Figure 9) with their specific color acuity endpoints as measured by the maximum distance (Figure 10) for detecting that Dyop color/contrast permutation as spinning. Note that this experimentation was done with a limited understanding of the visual effects of color perception or realization that the inclusion of Yellow (Amber) in the matrix was not a representation of visual processes since there are NO Yellow-receptive photoreceptors.

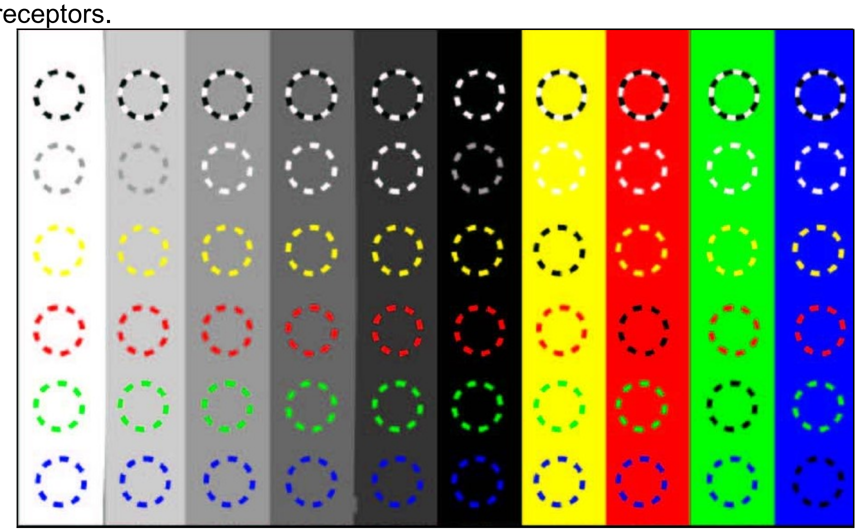


Figure 9: Initial 2010 Dyop Color Matrix with 60 color/contrast permutations.

	White/G1	Gray2	Gray3	Gray4	Gray5	Black/G6	Amber	Red	Green	Blue
G1/G1	g6_g1	g6g1_g2	g6g1_g3	g6g1_g4	g6_g5	g1_g6	g1g6 _amber	g1g6 _red	g1g6 _green	g1g6 _blue
Rotation Detection Distance	23	22	20	21	21	22	25	23	24	21
G3/G1	g3_g1	g3_g2	g1_g3	g1_g4	g1_g5	g3_g6	g1_amber	g1_red	g1_green	g1_blue
Rotation Detection Distance	26	30	23	23	25	24	38	24	27	22
Amber	amber_g1	amber_g2	amber_g3	amber_g4	amber_g5	amber_g6	g6_amber	g6_red	amber _green	amber _blue
Rotation Detection Distance	40	32	24	23	22	23	22	23	30	23
Red	red_g1	red_g2	red_g3	red_g4	red_g5	red_g6	red_amber	g6_red	red_green	red_blue
Rotation Detection Distance	25	28	34	27	25	24	24	27	23	29
Green	green_g1	green_g2	green_g3	green_g4	green_g5	green_g6	Green _amber	green _red	g6 _green	green _blue
Rotation Detection Distance	28	40	28	23	22	22	32	23	23	24
Blue	blue_g1	blue_g2	blue_g3	blue_g4	blue_g5	blue_g6	blue _amber	blue _red	blue _green	g6 _blue
Rotation Detection Distance	25	28	34	34	27	25	24	30	23	27

Figure 10: Initial 2010 Dyop Color Matrix with 60 color acuity endpoints with the visual threshold endpoint distances in feet.

The 2010 color/contrast matrix of 60 permutations was simplified in 2014 to a smaller range of 34 color/contrast combinations and compared as to the acuity endpoint for an individual with known "normal" vision and someone with known dyslexia. The color/contrast studies suggested that the maximum color/contrast disparity for individuals with a personal or family history of dyslexia was the acuity endpoints for **Green-on-White Dyop** versus a **Blue-on-Black Dyop**.

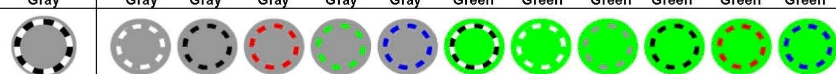
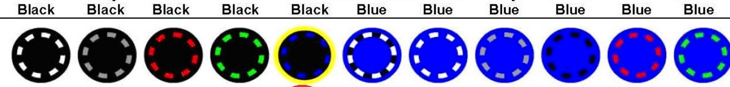
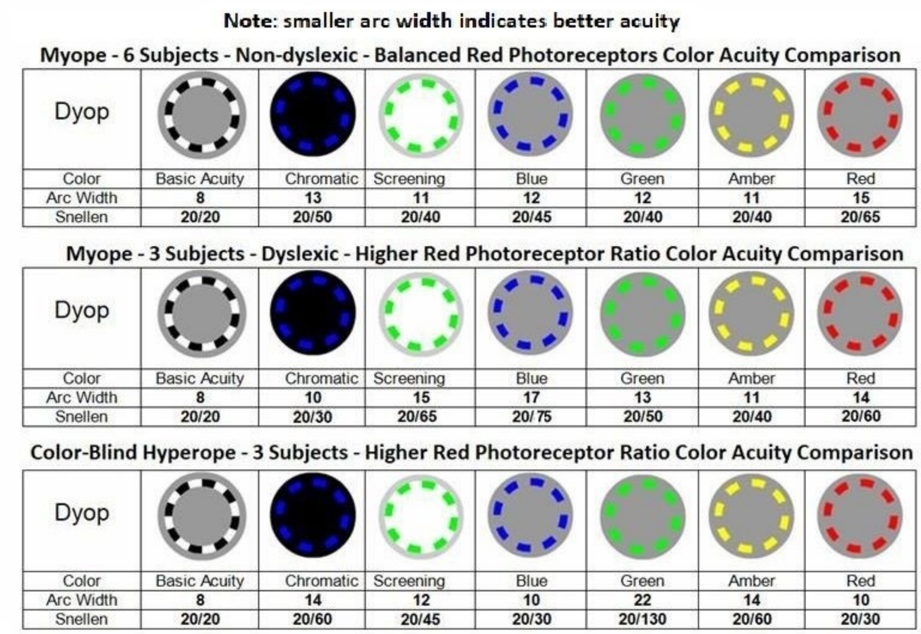
	Foreground Background	Black White	Gray White	Red White	Green White	Blue White	Black/White Red	White Red	Gray Red	Black Red	Green Red	Blue Red
	Dyop® image											
Arc Width Endpoint	**Normal** Dyslexic **Difference**	**8.7** 9.1 **-0.4**	**10.2** 10.2 **0.0**	**10.2** 11.3 **-1.1**	**12.7** **15.2** **-3.5**	**9.6** 10.7 **-1.1**	**8.5** 7.9 **+0.6**	**10.2** 9.0 **+1.2**	**15.8** 11.3 **+3.5**	**10.7** 12.1 **-1.4**	**11.3** 11.3 **0.0**	**11.3** 13.8 **-2.5**
Foreground Background	Black/White Gray	White Gray	Black Gray	Red Gray	Green Gray	Blue Gray	Black/White Green	White Green	Gray Green	Black Green	Red Green	Blue Green
Dyop® image												
Normal Dyslexic **Difference**	**7.6** 8.2 **-0.6**	**10.4** 9.0 **1.4**	**10.2** 8.2 **2.0**	**14.4** 15.2 **-0.8**	**11.6** 13.0 **-1.4**	**11.0** 17.2 **-6.2**	**9.0** 9.6 **-0.6**	**12.7** 11.3 **1.4**	**11.8** 12.1 **-0.3**	**9.9** 11.3 **-1.4**	**11.8** 12.1 **-0.3**	**10.2** 12.1 **-0.9**
	Foreground Background	White Black	Gray Black	Red Black	Green Black	Blue Black	Black/White Blue	White Blue	Gray Blue	Black Blue	Red Blue	Green Blue
	Dyop® image											
Arc Width Endpoint	**Normal** Dyslexic **Difference**	**7.9** 8.2 **-0.3**	**9.0** 9.6 **-0.6**	**8.7** 9.0 **-0.3**	**8.5** 8.2 **0.3**	**18.0** **10.2** **7.8**	**8.2** 7.9 **0.3**	**8.2** 8.2 **0.0**	**10.4** 9.6 **0.8**	**18.9** 14.4 **4.5**	**9.3** 12.1 **-2.8**	**8.7** 10.2 **-1.5**

Figure 11: Abbreviated 2014 Dyop Color Matrix with 34 color/contrast permutations. Values are Dyop arc minute widths.

The 2014 Dyop color/contrast 34 permutations (Figure 11) were further simplified in 2017 to a smaller range of 7 color/contrast permutations (Figure 12) with the emphasis on comparing basic acuity with a "neutral gray background" to the color acuity for red, green, blue, and yellow. Also included is the disparity as to a **Green-on-White Dyop** versus a **Blue-on-Black Dyop** acuity endpoints as a screening test for individuals with no known reading impairment versus those with known and diagnosed dyslexia. **Amber-on-Gray** is included as a potential test for future use in glaucoma diagnosis, although there is no **Amber** photoreceptor.


Note: smaller arc width indicates better acuity

Myope - 6 Subjects - Non-dyslexic - Balanced Red Photoreceptors Color Acuity Comparison

Dyop							
Color	Basic Acuity	Chromatic	Screening	Blue	Green	Amber	Red
Arc Width	8	13	11	12	12	11	15
Snellen	20/20	20/50	20/40	20/45	20/40	20/40	20/65

Myope - 3 Subjects - Dyslexic - Higher Red Photoreceptor Ratio Color Acuity Comparison

Dyop							
Color	Basic Acuity	Chromatic	Screening	Blue	Green	Amber	Red
Arc Width	8	10	15	17	13	11	14
Snellen	20/20	20/30	20/65	20/75	20/50	20/40	20/60

Color-Blind Hyperope - 3 Subjects - Higher Red Photoreceptor Ratio Color Acuity Comparison

Dyop							
Color	Basic Acuity	Chromatic	Screening	Blue	Green	Amber	Red
Arc Width	8	14	12	10	22	14	10
Snellen	20/20	20/60	20/45	20/30	20/130	20/60	20/30

Figure 12: Simplified 2017 **Chart2020** Dyop Color Matrix with 7 color/contrast permutations. Values are Dyop arc minute widths.

To further refine and simplify the color/contrast screening test a qualitative dual Dyop comparison test was created with only a spinning **Green-on-White Dyop** and spinning **Blue-on-Black** Dyop for use on an iPad, iPhone, or PC. (Figure 13.)

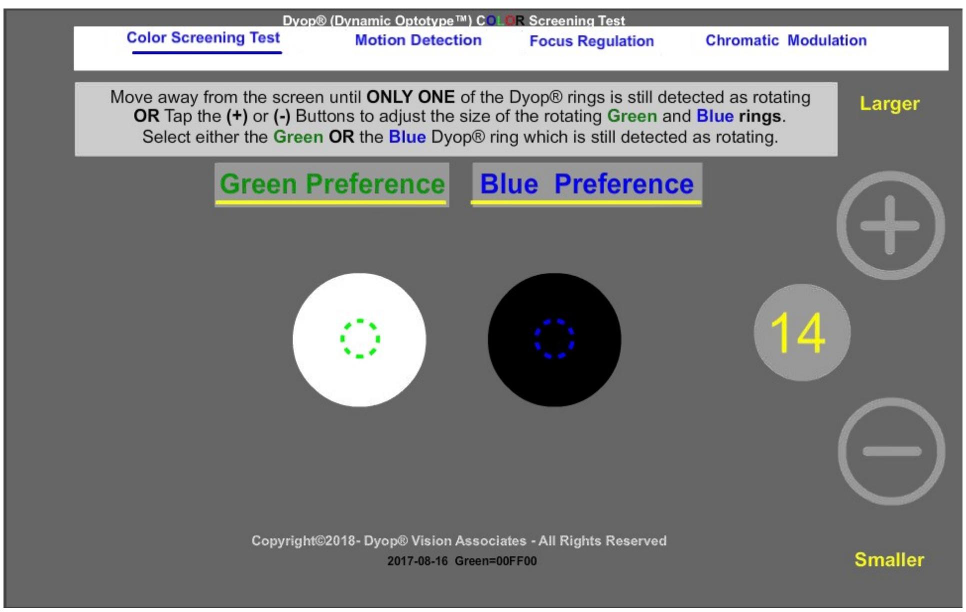


Figure 13: Dyop 2014 Dual Color Matrix for use on an iPad or iPhone or PC with 2 color/contrast permutations.

In anecdotal research by Dyop Vision Associates, using the online iPhone 2014 Dyop Dual Color dyslexia screening test, and with about 1200 individuals, approximately 800 individuals preferentially saw the spinning **Green-on-White Dyop** while approximately 400 individuals preferentially detected the smaller spinning **Blue-on-Black Dyop**. Of those approximately 400 positive responses who preferentially saw only the smaller spinning **Blue-on-Black Dyop**, about 350 of those individuals (about 85% of that group) also had personal or family symptoms of dyslexia, migraines, and/or epilepsy and about 50 (about 15% of that group) individuals had associated literacy problems even if they were not aware it was associated with dyslexia. Their symptomatic dyslexic response is likely from "chromatic" dyslexia where the disparity in the focal depth leads to visual stress at near distances.

Of the approximately 800 individuals who preferentially saw the spinning **Green-on-White Dyop** only about 10 (about 1% of the total) claimed to be dyslexic. Their symptomatic dyslexic response is likely from strabismus rather than color-induced ("chromatic") dyslexia. Of the individuals who preferentially detected the spinning **Green-on-White Dyop** who claimed to have dyslexia, one of them was red-green color blind. One other individual of this group who preferentially detected the spinning **Green-on-White Dyop** claimed to have migraines, but also had a previous concussion which could have contributed to the migraines as opposed to color perception.

DATA COLLECTION

In 2017 the qualitative Dyop dual comparison color test was embedded in the Chart2020/Dyop vision software as part of the quantitative options for color comparison. (Figure 14.)

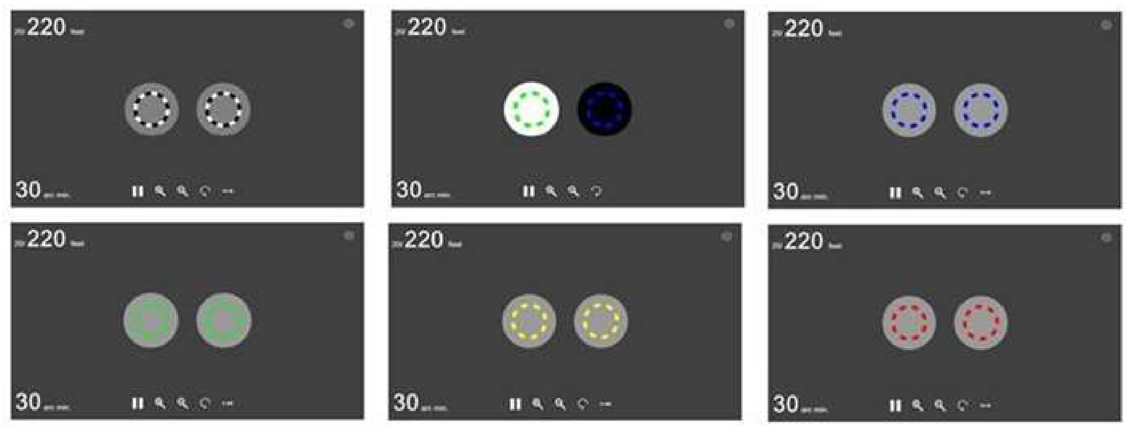


Figure 14: Chart2020 Dyop color/contrast permutations for Black/White, Blue, Green, Yellow, Red, and the "dyslexia duo."

Patients were initially presented with a display of both a spinning **Green-on-White Dyop** and a spinning **Blue-on-Black Dyop** with sufficient arc width diameter such that BOTH Dyop rings were detected as spinning. The Dyop rings were then reduced in arc width diameter until spinning of each of the identical diameter colored rings was not detected. (Figures 15, 16, 17, and 18.)

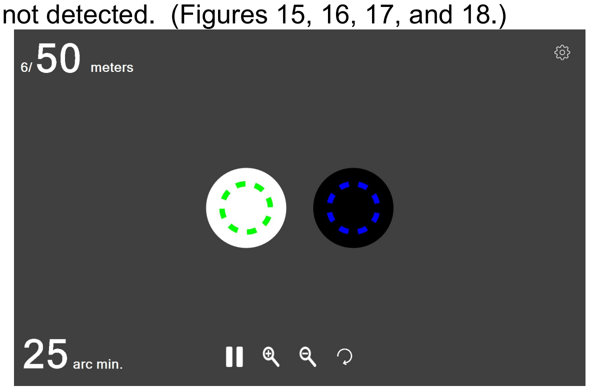


Figure15: PC Chart2020/Dyop test with Dual color/contrast permutations – 6/50 acuity setting.

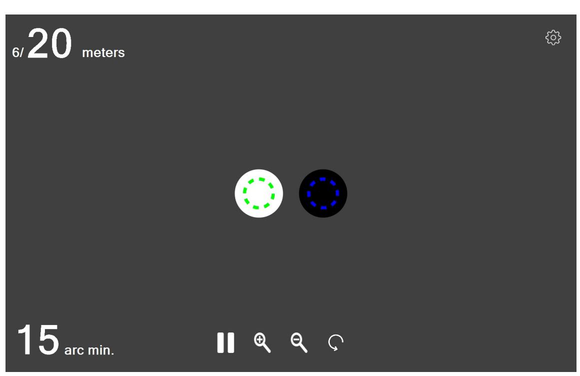


Figure 16: PC Chart2020/Dyop test with Dual color/contrast permutations – 6/20 acuity setting.

The smallest diameter ring where spinning was detected (corresponding to the metric acuity endpoint value) for each of the color/contrast combinations was recorded as its respective color acuity endpoint.

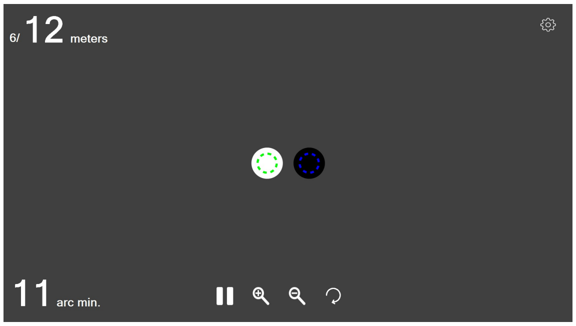


Figure 17: PC Chart2020/Dyop test with Dual color/contrast permutations – 6/12 acuity setting.

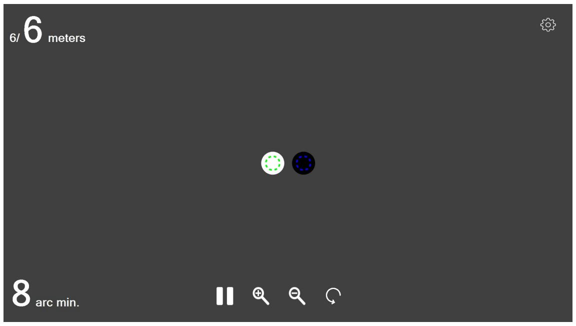


Figure 18: PC Chart2020/Dyop test with Dual color/contrast permutations – 6/6 acuity setting.

Data Collection and Statistical Analysis

Age Distribution

The 188 patients who were examined had a typical age range for pediatric optometry with the 95% of the individuals from age 9 through 18. (Figure 19.)

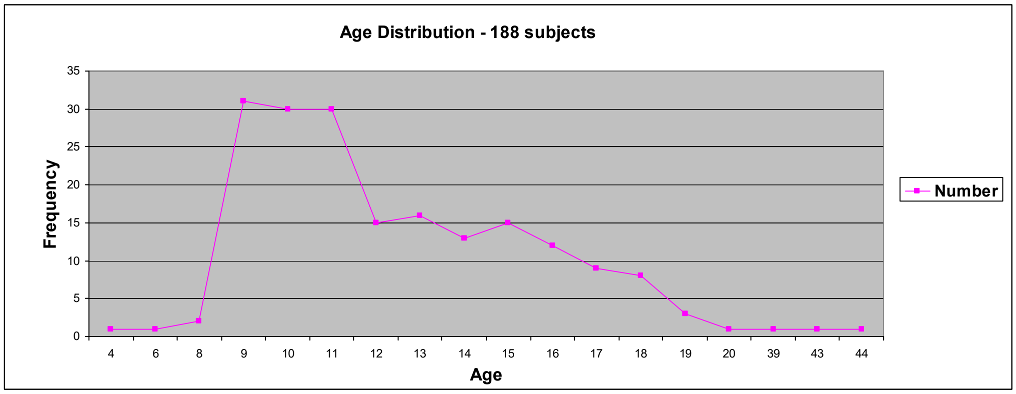


Figure 19: Age distribution of dyslexia study individuals

Results

Of the 188 individuals examined, 166 individuals (87% of the total) were diagnosed with dyslexia and 22 individuals (13% of the total) were diagnosed as not having dyslexia. Of the 188 individuals examined, 117 of the individuals (62% of the total) were males who had diagnosed dyslexia, 47 of the individuals (25% of the total) were females who had diagnosed dyslexia, 9 individuals (5% of the total) were males with no diagnosed dyslexia, and 15 individuals (8% of the total) were females who were diagnosed as not having dyslexia. (Figure 20.)

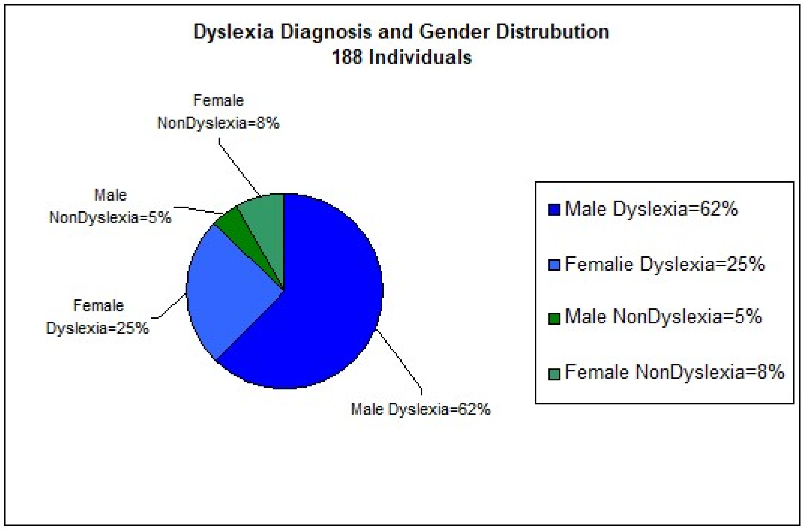


Figure 20: Gender distribution of dyslexia study individuals

Of the 166 individuals diagnosed with dyslexia, 5 (3%) were diagnosed with Dysnemkinesia, 36 (19%) were diagnosed with Dysphonesia, 18 (10%) were diagnosed with Dyseidesia, 37 (22%) were diagnosed with Dysphoneidesia, 29 (17%) were diagnosed as with Dysnemkinphonesia, 4 (2%) were diagnosed with Dysnemkineidesia, 32 (19%) were diagnosed with Dysnemkinphoneidesia, and 5 (3%) were diagnosed with Dyscalculia. (Figures 21, 22, 23, 24, and Table 2.) There were no individuals who were diagnosed as having Dysnomia.

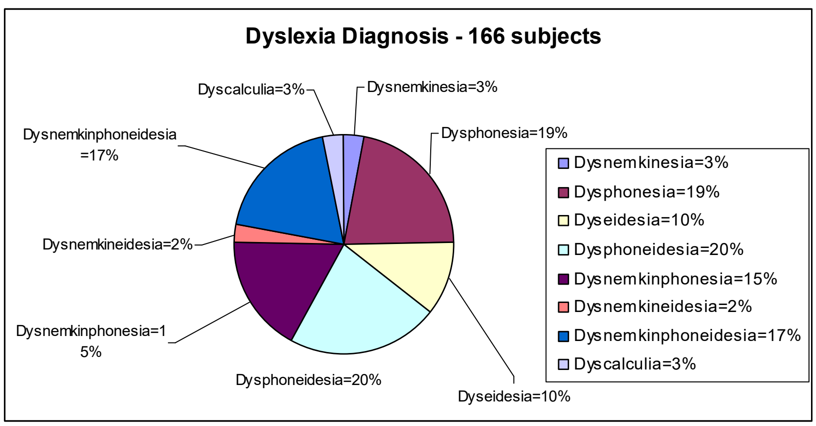


Figure 21: Distribution of dyslexia categories for the 166 diagnosed dyslexia individuals in the study

Response	Frequency	Percent	Green	Blue	Equal
Non-Dyslexic	22	12%	12	9	1
Dysnemkinesia	5	3%	0	4	1
Dysphonesia	36	19%	2	27	7
Dyseidesia	18	10%	0	17	1
Dysphoneidesia	37	20%	2	32	3
Dysnemkinphonesia	29	15%	2	25	2
Dysnemkineidesia	4	2%	0	4	0
Dysnemkinphoneidesia	32	17%	3	28	1
Dyscalculia	5	3%	0	5	0

Table 2: Distribution of dyslexia categories for the **188 individuals** in the study

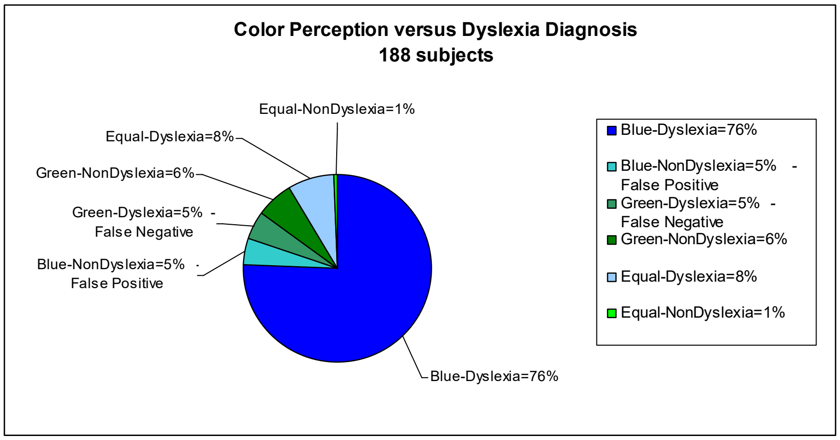


Figure 22: Dyslexia diagnosis versus Dyop color/contrast perception for 188 subjects

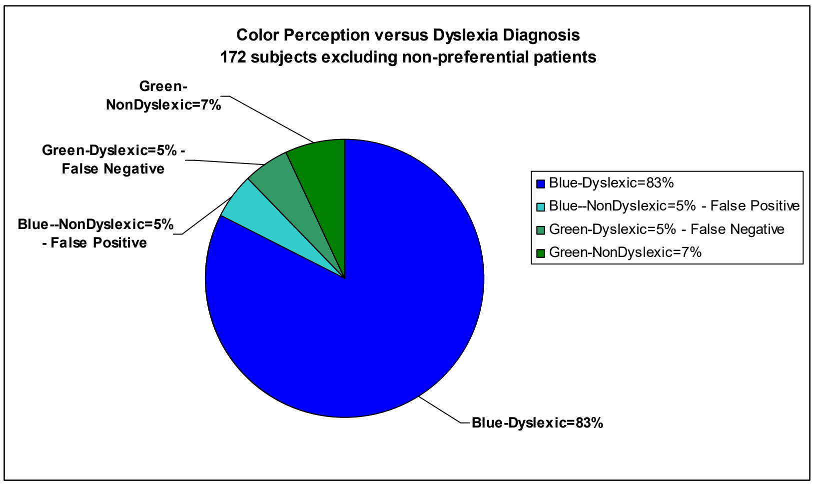


Figure 23: Dyop color/contrast perception versus dyslexia diagnosis for 172 subjects that had a definitive color response

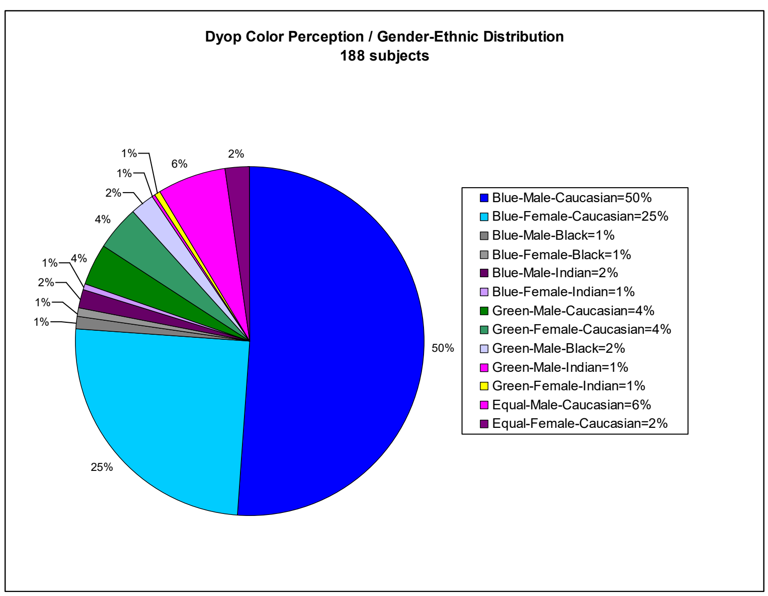


Figure 24: Dyop color/contrast perception per Gender and Ethnic Distribution for 188 subjects

Discussion

Human vision developed on the basis of resolution acuity for spotting predators and game rather than recognition acuity for comprehending culturally based letters. Rather than just Black and White, there is also a need to measure acuity as to the permutations of red, green, and blue inherent in the eye. The matrix of color permutations also varies among genetic groups with distinct attributes as to the ratio of L, M, S cone photoreceptor distribution.

The Dyop concept and test provides an almost unparalleled opportunity to subjectively measure resolution acuity and acuity in color. Measurement of acuity in color should allow a better understanding of visual processes as well as potentially lead to therapies based upon an individual's color perception.

Current Optometry and dyslexia visual standards primarily view dyslexia as a cerebral, in part due to the dependence on recognition acuity, rather than visual in origin, despite research indicating that the visual response of dyslexia precedes cerebral changes. Research with chromatic modulation in treating symptoms of migraines also indicates that the associated cerebral stress may have a visual origin as a result of the mechanics of color perception[2].

Inherent in this study is the realization that the patient population examined was limited to the sampling of patients specifically associated with an Optometric practice associated with dyslexia and dyslexia therapy and is not representative of society at large. As a result it is not representative of the incidence of dyslexia and associated symptoms of the general population. The high percentage of patients with dyslexia is due the realization and expectation of those patients and their parents of possible dyslexic symptoms. As such it would be advantageous and scientifically significant if a broader sample of patients were examined to see if the incidence of dyslexia, but known and unknown, was higher than the current estimates of 20% of the population.

The supposed incidence of dyslexia in letter-based cultures (Caucasian) is about 20% but may actually be higher due to individuals learning to compensate on their own for their reading disabilities. That incidence of 20% is similar in pictographic (Asian) cultures even though the associated cerebral impairment is on the right side of the brain rather than the left side impairment as in letter-based dyslexia[16].

It also might be beneficial to sample specific genetic groups as to their color response since anecdotal evidence has a much higher incidence of Red Focused Vision among Asian, Native American, and Native African gene pools. It might provide a "scientific" correlation for the predominant use of pictographic writing outside of Europe, much as the CAT scan activity of Caucasian (letter-based) dyslexics had reduced functioning in the left side of the brain while Asian (pictographic-based) dyslexics had reduced functioning in the right side of the brain[18].

What also needs to be resolved is the chicken and egg dilemma: is the higher red/green photoreceptor ratio of Red Focused Vision the cause of the cerebral disparity associated with dyslexia or is the higher red ratio of Red Focused Vision a retinal development induced by the cerebral functioning[19]?

Conclusions

This is a preliminary evaluation of the disparity of color perception versus diagnosed symptoms of dyslexia. There was a very strong positive correlation ($r \leq 0.9$) between color perception and diagnosed symptoms of dyslexia. The findings suggest that symptoms presented by dyslexics could be better understood or analyzed by their color perception.

This Dyop color/contrast clinical validation was intended to clinically validate the **qualitative** Dyop duo color/contrast test as used anecdotally on an iPhone. The test results, in comparison to diagnosed symptoms of dyslexia, indicate that there is an 80% up to a 90% correlation of a disparity in color perception to the etiology of dyslexia as to the acuity endpoints for a **Green-on-White** versus a **Blue-on-Black Dyop**.

We have no relevant financial or non-financial relationships to disclose.

Recommendations

The prototype methodology for the Dyop color/contrast screening test used an iPhone with identical diameter **Green-on-White** and **Blue-on-Black Dyops.** That **qualitative** test forced the subject to choose ONLY ONE of the spinning Dyops as still visible. It prevented the option of both Dyops being equally visible as to spin detection and identical acuity endpoint.

The numerous instances of equal acuity endpoints for **Green-on-White** and **Blue-on-Black Dyops** in this research study indicate that the test was likely not properly understood by those subjects. A third category of L/M ratios where the endpoints are equal is unlikely since that was never observed in the initial anecdotal tests.

A more effective **quantitative** clinical study is recommended which would do an **initial** binocular acuity endpoint determination with a spinning **Black/White-on-Gray** Dyop to determine the acuity benchmark. That initial test would provide an acuity benchmark, but it would also familiarize subjects to the Dyop test methodology. Then a spinning **Green-on-White Dyop** and a spinning **Blue-on-Black** Dyop would be tested individually to determine their specific acuity endpoints and provide more reliable values for their comparison as to their possible correlation with symptoms of dyslexia, migraines, and epilepsy.

Because this study was limited to patients who predominantly were seeing an Optometric practice which specialized in dyslexia and dyslexia therapy, future studies would be enhanced by including a broader group of individuals who were not specifically associated with dyslexic symptoms.

This study was also based on the **qualitative** comparison as to the color/contrast response and relative perception of a **Blue-on-Black Dyop** versus a **Green-on-White Dyop.** A **quantitative** clinical study of color acuity should provide better validation of the syndromes associated with dyslexia and variances in color acuity as well as provide validation for the mechanism of accommodation by comparing the relative endpoint for **Red-on-Gray**, **Green-on-Gray**, and **Blue-on-Gray Dyops**.

A suggested Dyop future research sequence should be:
1. Binocular acuity with a **Black/White-on-Gray Dyop**
2. Binocular acuity with a **Blue-on-Gray Dyop**
3. Binocular acuity with a **Green-on-Gray Dyop**
4. Binocular acuity with a **Red-on-Gray Dyop**
5. Binocular acuity with a **Blue-on-Black Dyop**
6. Binocular acuity with a **Green-on-White Dyop**

Note: those revised six acuity endpoint research questions are embedded in the Google Forms survey within the current Chart2020/Dyop test.

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