Article • A Comparison of Dyop Color Perception and Dyslexia Diagnosis

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ABSTRACT

Background: Acuity and accommodation result from an array 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. This study's objective was to compare the qualitative acuity responses of a specific Dyop color/contrast combination to diagnosed symptoms of dyslexia.

Methods: One hundred and eighty-eight patients, ranging in age from 4 years to 44 years, were examined as patients of the Stark-Griffin Dyslexia Academy to compare their relative 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 Stark-Griffin Dyslexia Academy trains eye care professionals as to how to diagnose and treat patients with potential symptoms of dyslexia. The patients were diagnosed as to their prevalent type of dyslexia, if any, through the Stark-Griffin Dyslexia Assessment. The patients were then presented with, 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 identically sized Dyop rings were then reduced in arc width until spinning of each of the 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 the 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 the 166 patients diagnosed with dyslexia, 151 patients (86% of that group) detected a smaller angular arc width diameter for the spinning blue-on-black Dyop, while 9 patients (5% of that group) detected a smaller angular arc width diameter for 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) detected a smaller angular arc width for the spinning green-on-white Dyop, while 9 patients (41% of that group) detected a smaller angular arc width for the spinning blue-on-black Dyop. Of the 22 patients diagnosed as not having dyslexia, one was diagnosed as "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) which responded by detecting identical acuity endpoints for both the green-on-white Dyop and the blue-on-black Dyop. Of the patients who detected an identical acuity endpoint for both color options, 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%) detected a smaller angular arc width for the spinning blue-on-black Dyop. Of the 21 patients with a definitive color response and diagnosed as not having dyslexia, 12 (57%) detected a smaller angular arc width for the spinning green-on-white Dyop. While this is only a preliminary study, the correlation of detecting a smaller angular arc width for a spinning blue-on-black Dyop with the 86% association with diagnosed dyslexia definitely deserves further evaluation.

Conclusions: This preliminary evaluation of the disparity of color perception versus diagnosed symptoms of dyslexia showed a strong positive association (~86%) 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

Acuity is a learned process resulting from the combined stimuli of the retinal red (L), green (M), and blue (S) photoreceptors (Figure 1). The focal depth for red, green and blue modulates that photoreceptor response (Figure 2). Changes in the shape of the optical lens has as a primary function the focusing of light on the retina to optimize the response of those photoreceptors. Changes in the population ratio of red, green, and blue photoreceptors also seem to modulate that focal response (Figure 3).

Acuity Standards

Current visual acuity standards are based upon the relative cognition of European-style letters, which provide a visual target to assess acuity and refractive error as developed and copyrighted in 1862 by Dr. Herman Snellen.[1] The Snellen chart typically consists of multiple rows of letters viewed at a testing distance of 6 meters (20 feet) such that each letter on the 6/6 (20/20) Snellen visual acuity line subtends 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 English alphabet and fonts have the advantage of being almost universally recognized within Europe and relatively simple to administer. Since Snellen optotypes are no longer in copyright, they also have the advantage for eye care professionals and optotype vendors that they 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.[2]

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. They 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 Cs (or rings), tumbling Es, numbers, children's symbols (Allen figures), HOTV charts, or LEA symbols (Figure 4).

The letter-based recognition acuity tests, however, have a disadvantage in that cultures with a pictographic literacy preference find testing using letter-based literacy is an impediment. Acuity testing with letter-based optotypes is also an impediment for infants and non-literate individuals. Letter-based tests are also inherently imprecise due to the inconsistency of their visual stimulus areas. Letter-based acuity testing using black optotypes on a white background ignores the fact that acuity is a color function of the red, green, and blue photoreceptors. Letter-based testing ignores that the ratio of red, green, and blue photoreceptors may not be uniform among humans. Testing with static optotypes ignores the potential of image fixation, which might possibly lead to a refraction overminus.[3]
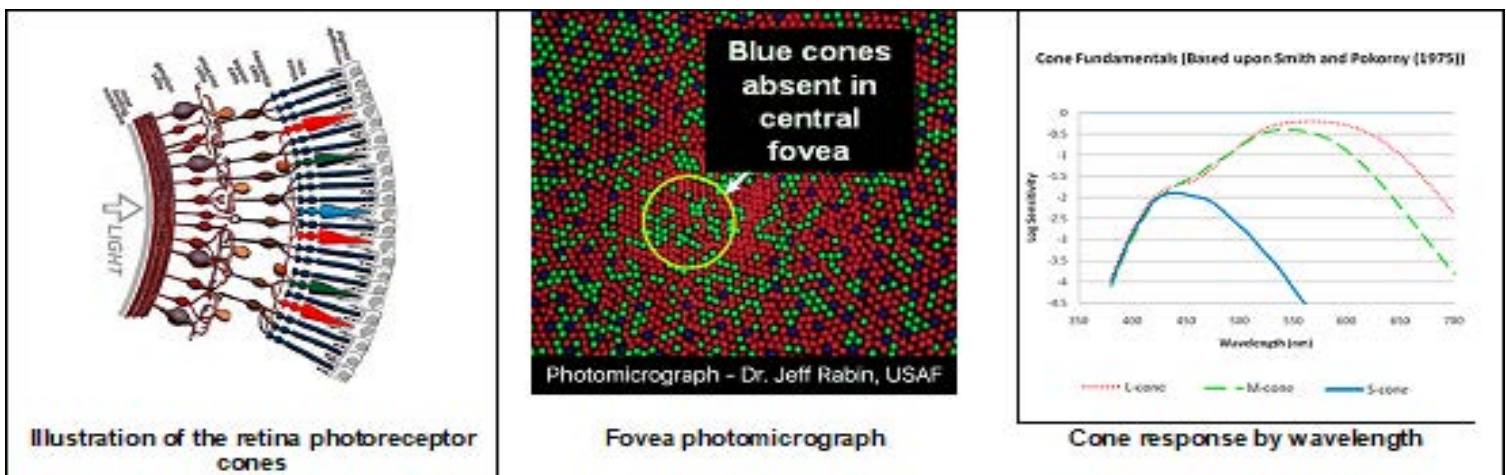

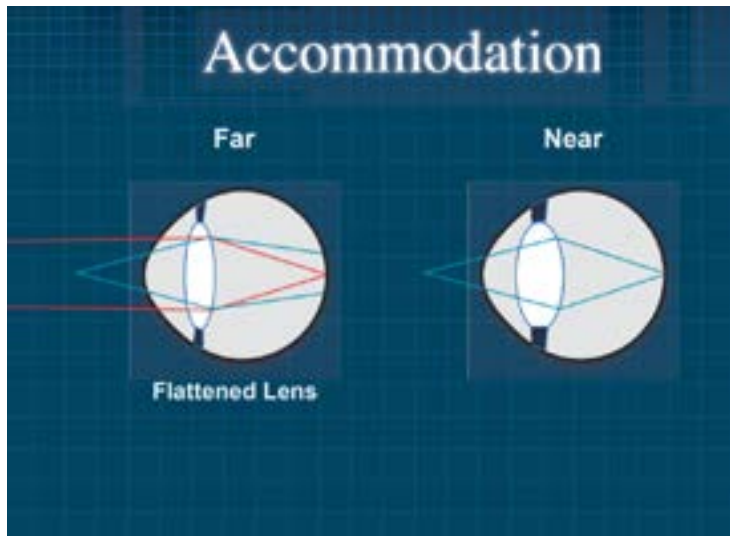**Figure 1.** *Photoreceptor sensitivity to the range of light by the retina cones*

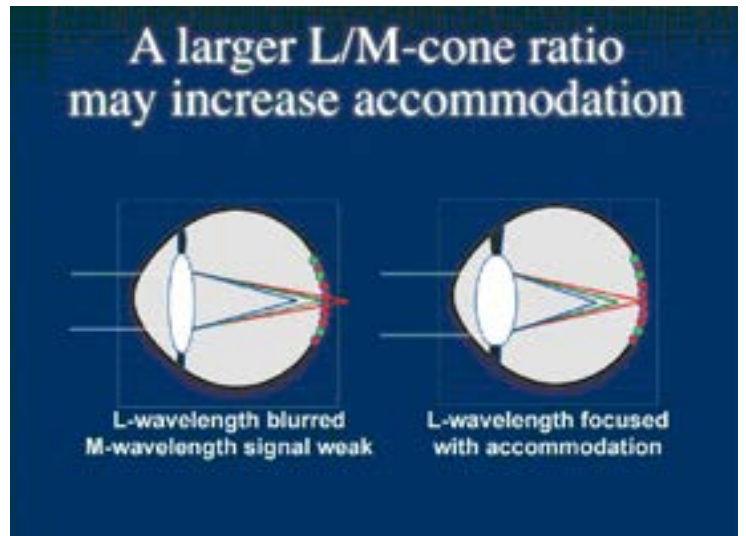Figure 2. *Accommodation as produced by the lens shape*

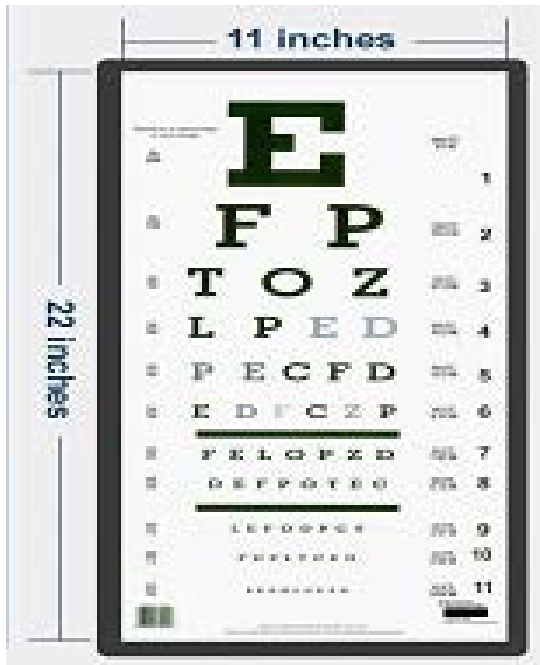Figure 3. *Effect of the L/M cone ratio*

Figure 4. *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.)*
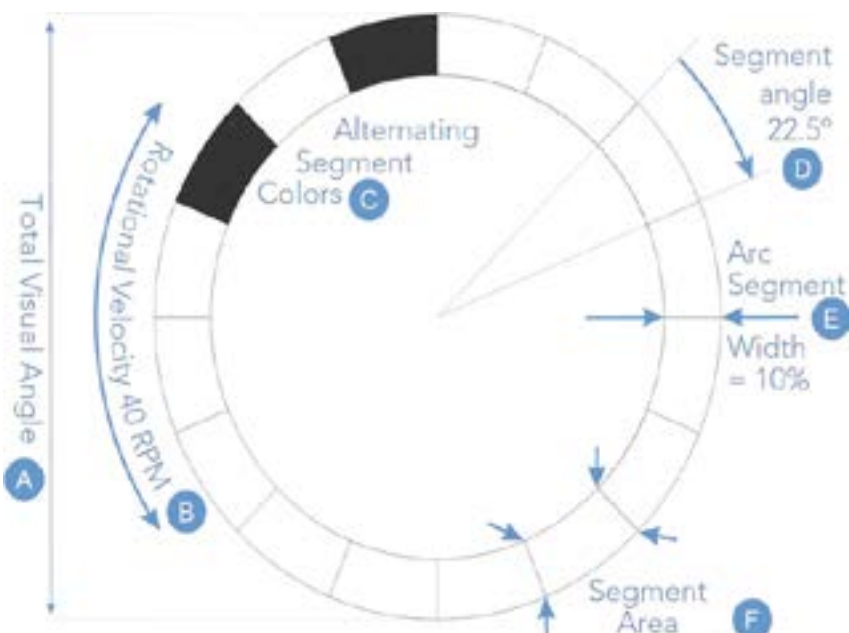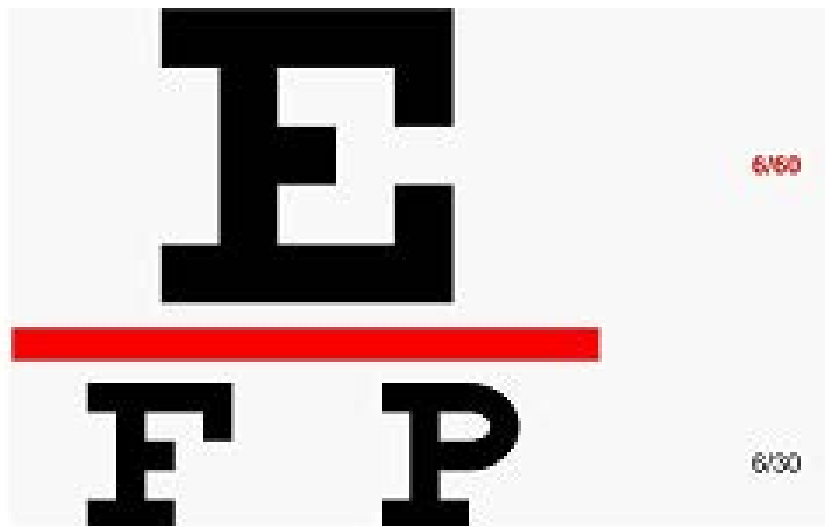

Figure 5. *This illustrates the fundamental features of the Dyop (dynamic optotype) acuity chart: the total circular diameter or visual angle (A), speed of rotation (B), contrasting colors in black and white (C), segment angle (D), segment arc width (E), and area of each segment in minutes squared of arc (F).[4]*
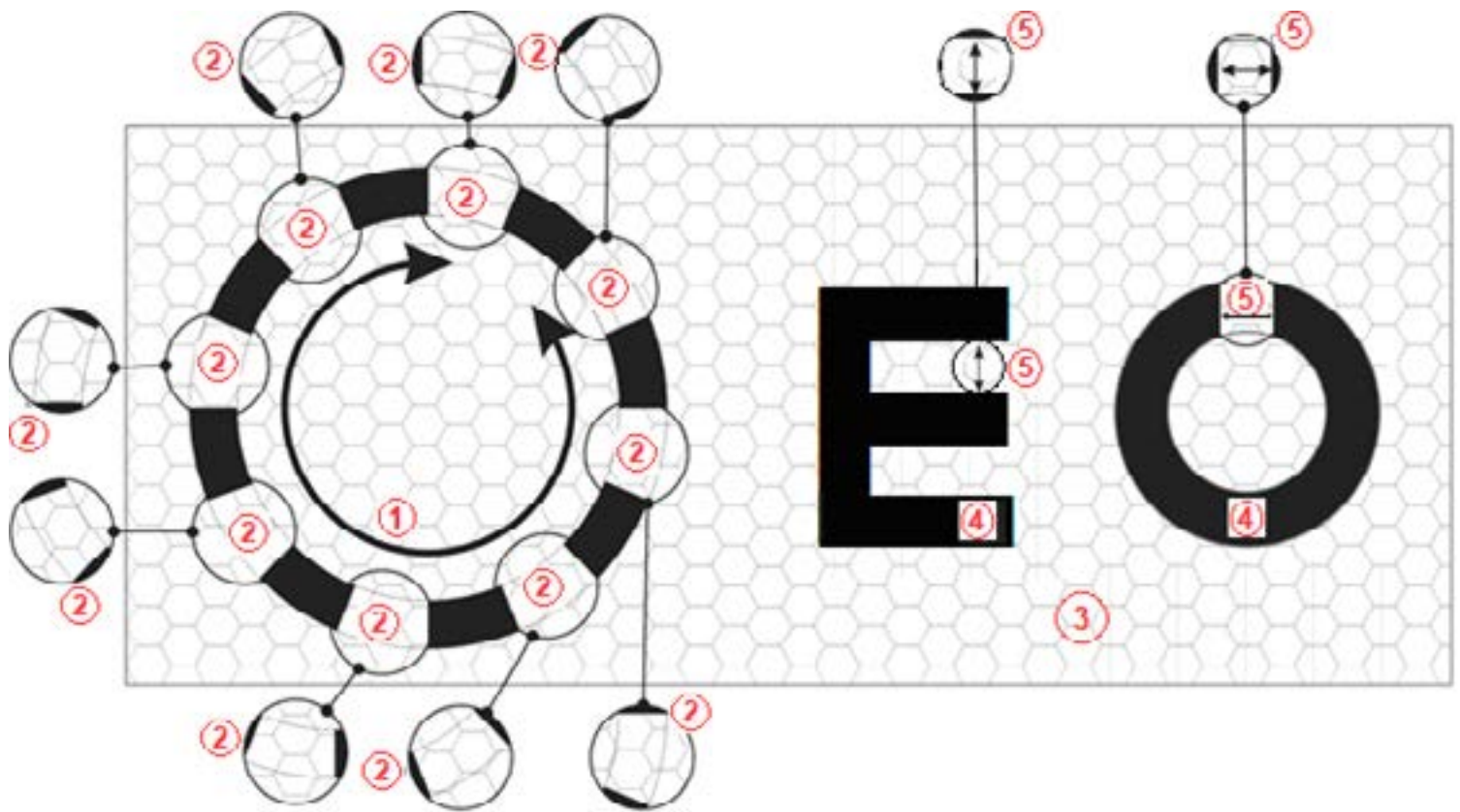
Figure 6. *Display of the moving segmented areas of a Dyop and the resultant moving, stimulated individual areas superimposed on the retina.[5]*
Item 1 – visual angular velocity or strobic contrast response
Item 2 – a moving segment visual arc-area dynamically stimulating retina cells with motion
Item 3 – retinal cells
Item 4 – an example of a static historical optotype
Item 5 – a static minimum angle of resolution of a historical optotype

Dyop Acuity Measurement

In 2008, Allan Hytowitz discovered that a uniformly spinning segmented ring could provide a strobic visual optotype stimulus, 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 the strobic pixelized refresh rate of the photoreceptors as an indicator for visual acuity and other functional parameters for determining refractions[4] (Figure 5).

Because Dyop acuity and refractive measurements are not dependent upon cultural cognition of letters, a Dyop test could also be used for infants, non-literate, 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 Dyop has a significantly sharper acuity endpoint threshold based upon the angular arc width and viewing distance. A typical Dyop segmented ring comprises 8 black and 8 white equally sized, alternating segments on a neutral gray background, spinning at 40 rotations per minute, with a 10% gap/segment stroke width.[5] 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 do static optotypes, which depend upon small eye motions (saccades) to help refresh the photoreceptors (Figure 6).

Visual Stimulus Comparison

Harris and Keim[6] investigated the accuracy of the Dyop acuity test with 162 participants by assessing the threshold acuities on a fully randomized basis, using Sloan letters and Dyop doublets with the following test conditions: uncorrected refraction and corrected refraction with +2.00 lens, +3.00 lens, and +4.00 lens. There was a very strong linear Pearson correlation between Sloan and Dyop acuity measures for all of 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
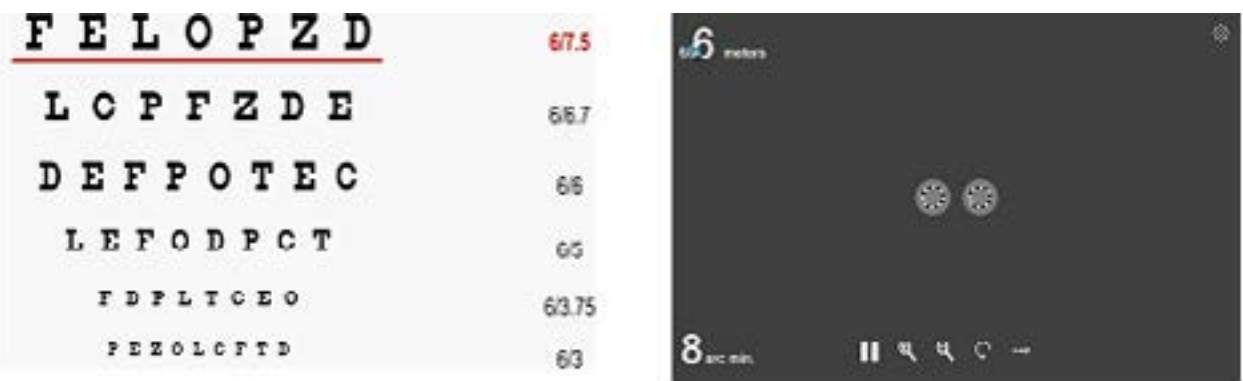
Figure 7. *A comparison of Snellen and Dyop acuity charts (source: Chart2020® version 10.3.6 computerized visual acuity unit)*

and 0.035 for a projected Sloan letter and a Dyop doublet, respectively.

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

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

The optimal Dyop comparable to the Snellen 6/6 (20/20) acuity had an empirically determined minimum area of resolution (MAR) stimulus area of 0.54 arc minute squared versus the standard Snellen stimulus gap (MAR) of 1.00 arc minute squared. That disparity of a linear Dyop versus logarithmic Snellen MAR correlates to the Snellen gap having twice the area of the empirically measured Dyop gap. That MAR disparity also likely contributes to the higher variance of a Snellen acuity test versus a Dyop acuity test.

Dyop acuity testing is also typically six times as precise as the Snellen test, with one-sixth the variance and with twice the efficiency (primarily due to the precision of the perception threshold). The black/white-on-gray Dyop contrast also maximizes the strobic photoreceptor stimulus and minimizes the effects of ambient light on acuity measurement. The 40 RPM strobic photoreceptor stimulus of the spinning Dyop gap/segment seems to match 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 comparison (spinning or not-spinning) while there are a potential of 26 possibilities with Snellen letter targets.

Categories of Dyslexia

Dyslexia seems to have little to do with intelligence or limited intelligence.[7] Instead, it is primarily a reduced ability to read letter-based words, which may be caused by visual stress. Rather than "letter reversals," the symptoms of dyslexia are typically unstable letter images, which impede decoding words from the combinations of letters.[8] The letter-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 (Figure 8, Table 1).[9]

Table 1. Diagnostic Categories of Dyslexia[10]

| Code	Types of Dyslexia	Symptom	Combos
1	Dysnemkinesia	Motor skills	
2	Dysphonesia	Auditory	
3	Dyseidesia	Visual	
4	Dysphoneidesia	Auditory & visual	2 & 3
5	Dysnemkinphonesia	Motor & auditory	1 & 2
6	Dysnemkineidesia	Motor & visual	1 & 3
7	Dysnemkinphoneidesia	Motor, auditory, & visual	1, 2, & 3
8	Dysnomia	Name retrieval	
9	Double deficit	Auditory & name retrieval	2 & 8
10	Dyscalculia	Math difficulty	
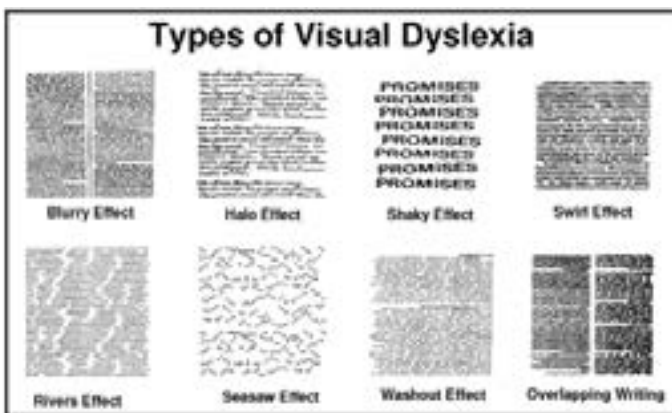
Figure 8. *Representation of the visual instability associated with dyslexia*
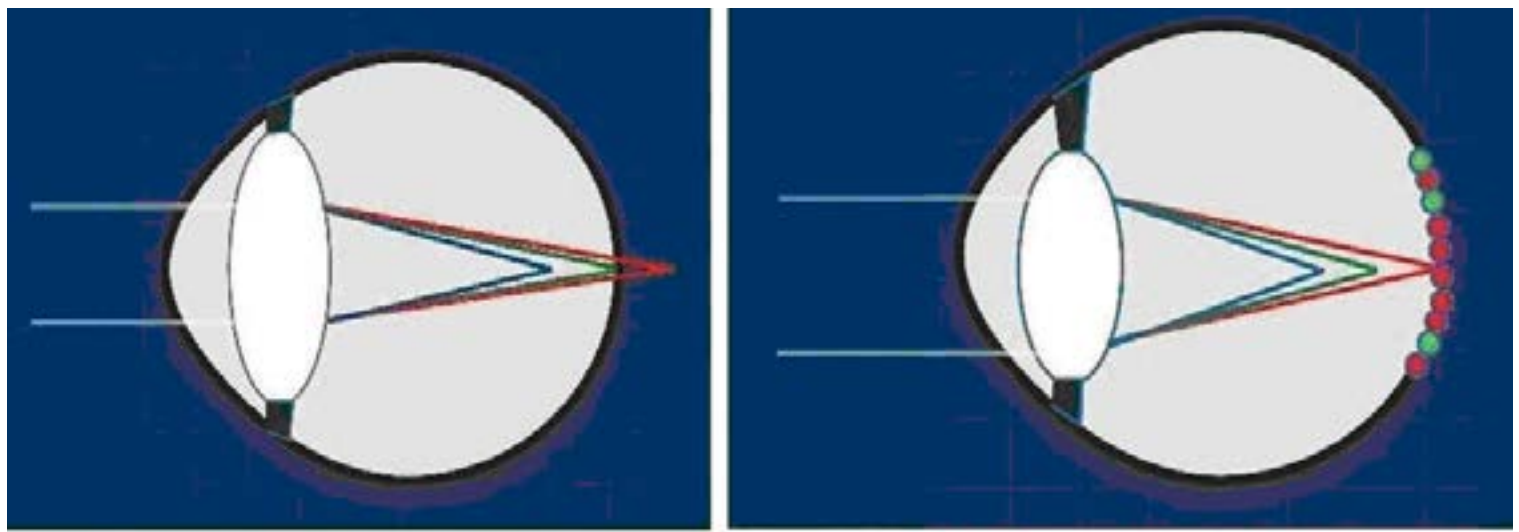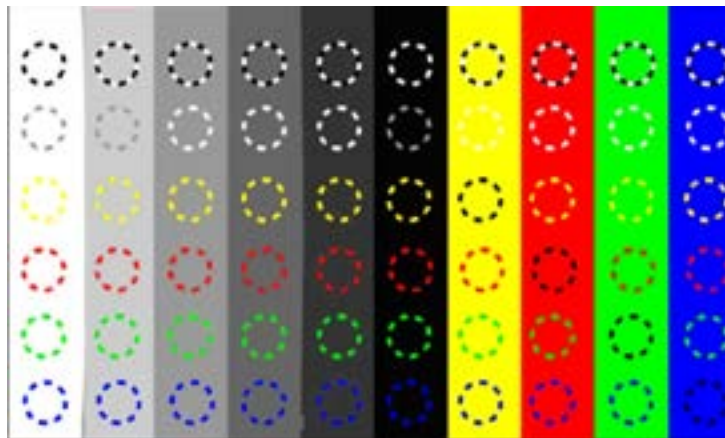
Green Focused Vision (GFV)
50% Red and 45% Green photoreceptors

Red Focused Vision (RFV)
75% Red and 20% Green photoreceptors

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

	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. Dyop color array with 60 color/contrast permutations (top) and associated color acuity endpoints in feet (bottom)

L/M Ratio Disparity and "Slow Readers"

Numerous research projects have attempted to correlate color perception and symptoms of dyslexia using colored overlays to tint the apparent text background and hopefully increase legibility and cognition.[11] In 2007, Dr. Chris Chase of Western University in Pomona, CA discovered a correlation between the L/M ratio of photoreceptors and reading fluency in children.[12] Variances in the L/M photoreceptor ratio seem to correlate with disparities in the focal stability of near and far images. A higher L/M ratio (75% red and 20% green) tends to produce a more stable distance image, while a lower L/M ratio (50% red and 45% green) tends to produce a more stable near image (Figure 3). (The other 5% in both groups were the blue photoreceptors.) The more stable distance image has been associated with a relatively unstable near distance image and symptoms of subjects being "slow readers," i.e., dyslexic.[13]

The acuity 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 (Figure 9).[12] 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 providing a more stable near image for 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.

The 2010 color/contrast array of 60 permutations was modified in 2014 to a smaller selection of 34 color/contrast combinations to compare the acuity endpoint for an individual with known "non-dyslexic" vision versus someone with known dyslexia. That color/contrast study suggested that the maximum color/contrast disparity for individuals with a personal or family history of dyslexia was the acuity endpoint for a green-on-white Dyop versus the acuity endpoint for a blue-on-black Dyop.

The 34 Dyop color/contrast permutations from 2014 (Figure 11) were further simplified in 2017 as an array of 7 color/contrast permutations (Figure 12), with the emphasis on comparing basic acuity with a "neutral gray background" with the Dyop acuity endpoints for the colors red, green, blue, and yellow. Included in the array were a green-on-white Dyop and blue-on-black Dyop, with their acuity endpoints being used as a screening test for individuals with no

Figure 11. *Abbreviated 2014 Dyop array with 34 color/contrast permutations. Values are Dyop angular arc minute diameters.*

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-Feet	20/20	20/50	20/40	20/45	20/40	20/40	20/65
Snellen-Meters	6/6	6/15	6/12	6/14	6/12	6/12	6/20

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-Feet	20/20	20/32	20/65	20/75	20/50	20/40	20/60
Snellen-Meters	6/6	6/9.5	6/20	6/23	6/15	6/12	6/18

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

Dyop Feet							
Color	Basic Acuity	Chromatic	Screening	Blue	Green	Amber	Red
Arc Width	8	14	12	10	22	14	10
Snellen-Feet	20/20	20/60	20/45	20/32	20/130	20/60	20/32
Snellen-Meters	6/6	6/18	6/14	6/9.5	6/40	6/18	6/9.5

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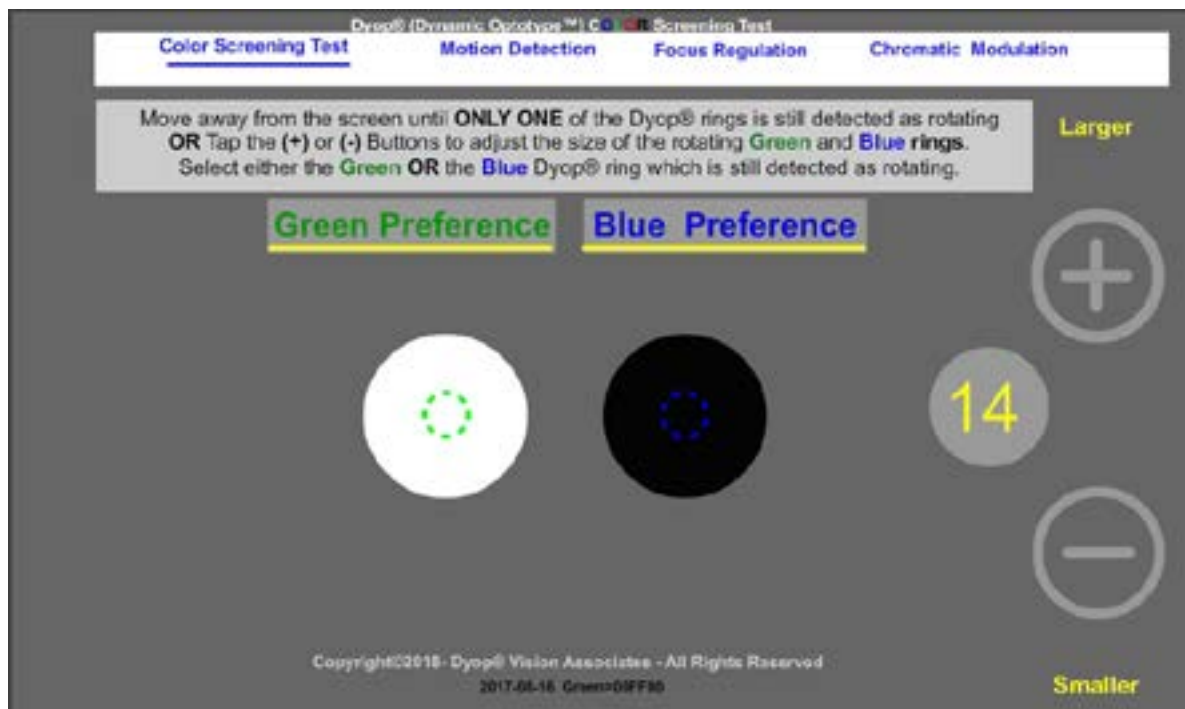

Figure 13. *Dyop Color/Contrast Duo for use on an iPad, iPhone, or PC with 2 permutations*

known reading impairment, versus those individuals diagnosed with symptoms of dyslexia. (Amber-on-gray was included as a potential test for future use in glaucoma diagnosis, although there is no amber photoreceptor.)

To increase the portability and simplify the color/contrast screening test, a qualitative dual Dyop comparison test was created with only a spinning green-on-white Dyop and a spinning blue-on-black Dyop for use on an iPad, iPhone, or PC (Figure 13). In anecdotal research by Dyop Vision Associates, using the online iPhone 2014 Dyop Color Duo as a dyslexia screening test, and with about 1200 individuals, approximately 800 individuals detected a smaller angular arc width for a spinning green-on-white Dyop, while approximately 400 of those individuals detected a smaller angular arc width for a spinning blue-on-black Dyop. Of those approximately 400 positive responses who detected a smaller angular arc width for a 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 individuals (about 15% of that group) had associated literacy problems even if they were not aware it was associated with dyslexia. Their symptomatic dyslexic response is likely what can be described as "chromatic dyslexia," where the disparity in the focal depth leads to visual stress at near distances.

Of the approximately 800 individuals who detected a smaller angular arc width for the spinning green-on-white Dyop, only about 10 (about 1% of the total) claimed to be "dyslexic." Their symptomatic "dyslexic" response is speculated as likely from strabismus rather than being color-induced ("chromatic") dyslexia. Of the individuals who had a lower acuity endpoint for the spinning green-on-white Dyop and who claimed to have dyslexia, one of them was red-green color blind. One other individual in this group who had a lower acuity endpoint for 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.

Methods

One hundred and eighty-eight patients, ranging from 4 years to 44 years in age, were randomly selected and examined as patients of the Stark-Griffin Dyslexia Academy, using standard dyslexia diagnostics and the Stark-Griffin Dyslexia Assessment.[17] Their diagnosis as to type of dyslexia was compared to their relative perception of the color/contrast acuity endpoint of a spinning green-on-white Dyop versus a spinning blue-on-black Dyop as part of the Chart2020 vision test platform. Their consent to Dyop testing was part of their dyslexia test participation.

The qualitative green-on-white versus blue-on-black Dyop comparison color test is embedded in the Chart2020/Dyop vision software as part of the options for color comparison (Figure 14). Patients were presented with a combined, identical-diameter display of a spinning green-on-white Dyop and a spinning blue-on-black Dyop, each with sufficient arc width diameter 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).

The smallest-diameter ring where spinning was detected (corresponding to the metric acuity endpoint value) for each of the color/contrast
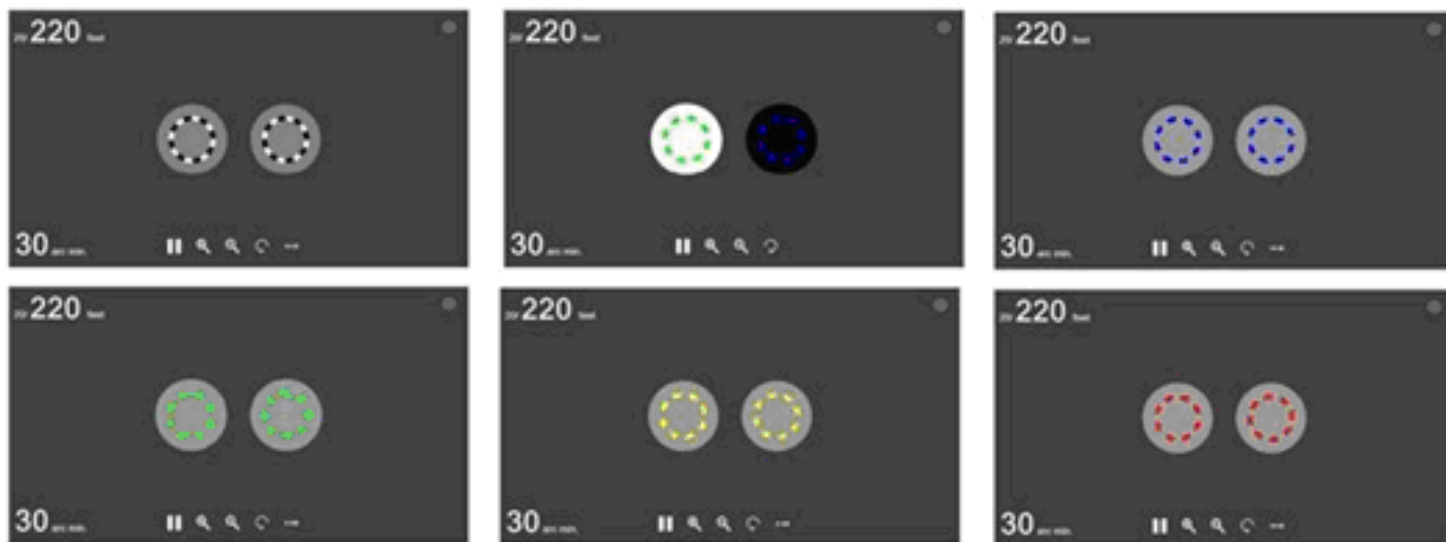

Figure 14. Chart2020 Dyop color/contrast permutations for black/white, blue, green, yellow, red, and the "dyslexia duo"
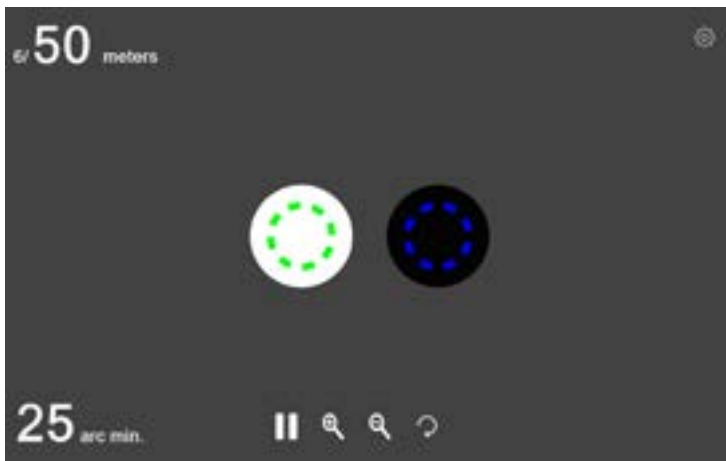
Figure 15. *PC Chart2020/Dyop test with dual color/contrast permutations – 6/50 acuity setting*

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

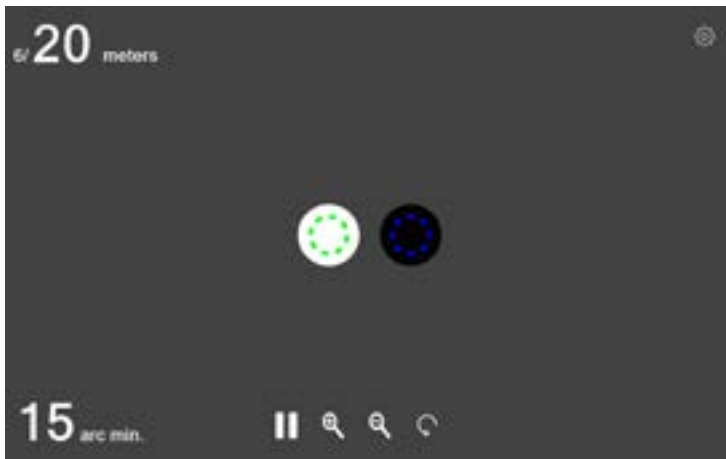**Figure 17.** *PC Chart2020/Dyop test with dual color/contrast permutations – 6/12 acuity setting*
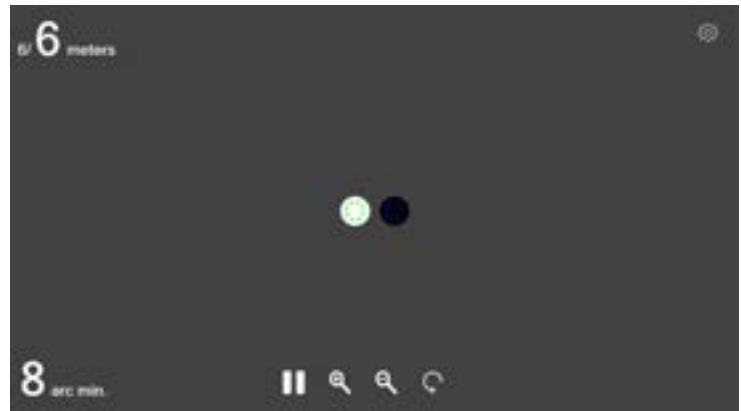
Figure 18. *PC Chart2020/Dyop test with dual color/contrast permutations – 6/6 acuity setting*

combinations was recorded as its respective color acuity endpoint.

Data Collection and Statistical Analysis
Age Distribution

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

Results

Of the 188 individuals examined, 166 individuals (87% of the total) were diagnosed with dyslexia, while 22 individuals (13% of the total) were diagnosed as not having dyslexia. Of the 188 individuals examined, 117 of those 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).

Of the 166 individuals diagnosed with dyslexia, 5 (3%) were diagnosed with dysnemkinesia, 36 (19%)
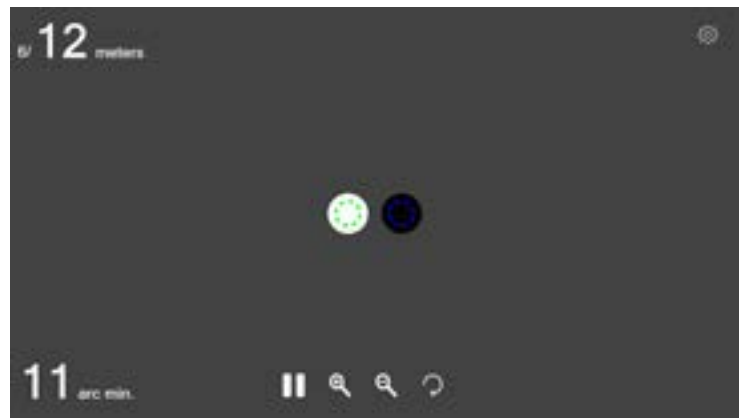
were diagnosed with dysphonesia, 18 (10%) were diagnosed with dyseidesia, 37 (22%) were diagnosed with dysphoneidesia, 29 (17%) were diagnosed with dysnemkinphonesia, 4 (2%) were diagnosed with dysnemkineidesia, 32 (19%) were diagnosed with dysnemkinphoneidesia, and 5 (3%) were diagnosed with dyscalculia (Table 2 and Figures 21, 22, 23, and 24). There were no individuals who were diagnosed as having dysnomia.

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 array 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 measure resolution acuity and acuity in color subjectively. Measurement of acuity in color should allow a better understanding
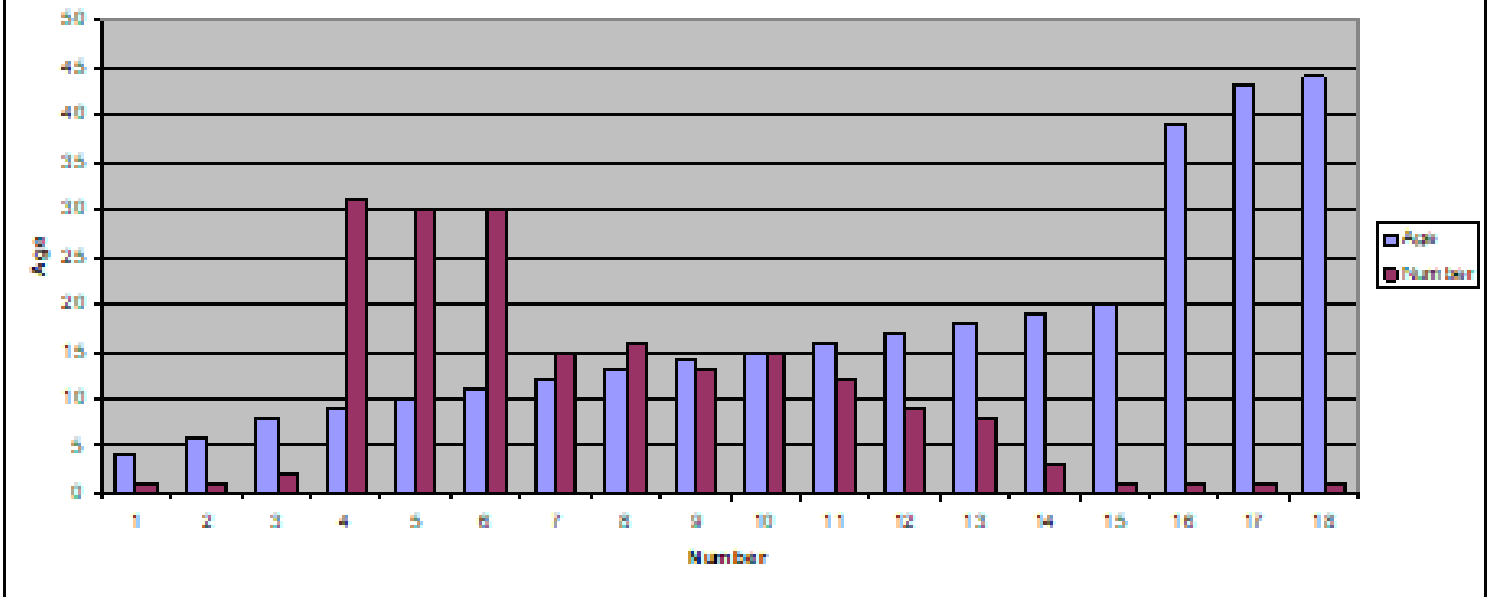
Figure 19. *Age distribution of dyslexia study individuals*
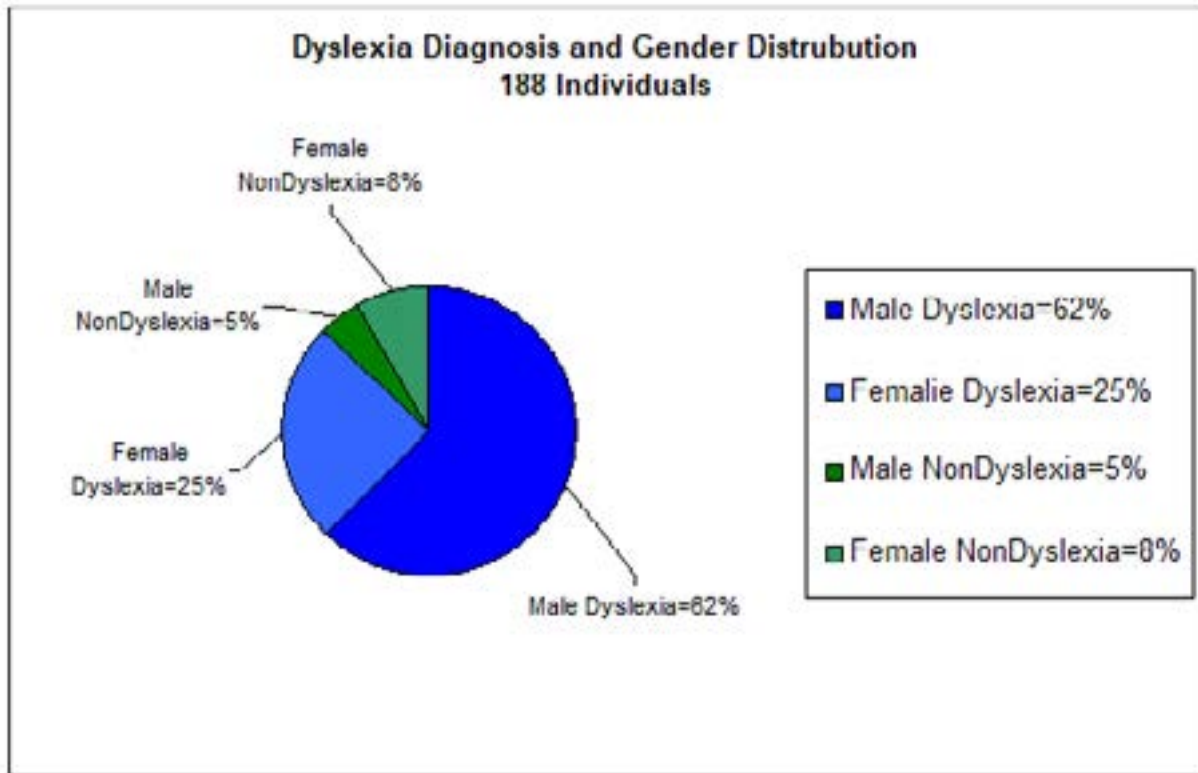

Figure 20. *Gender distribution of dyslexia study individuals*

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 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.[8]

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

Table 2. Distribution of Dyslexia Categories for the 188 Individuals in the Study Versus Dyop Color/Combination Relative Acuity Endpoint

Response	Frequency	% of Total	Better Acuity Green/White	Better Acuity Blue/Back	Equal Response	% Green/White	% Blue/Black	% Equal
Non-Dyslexic	22	12	12	9	1	55	41	5
Dysnemkineshia	5	3	0	4	1	0	80	20
Dysphonesia	36	19	2	27	7	6	75	19
Dyseidesia	18	10	0	17	1	0	94	6
Dysphonesidesia	37	20	2	32	3	5	86	8
Dysnemkinphoneisa	29	15	2	25	2	7	86	7
Dysnemkineidesia	4	2	0	4	0	0	100	0
Dysnemkinphoneidesia	32	17	3	28	1	9	88	3
Dyscalculia	5	3	0	5	0	0	100	0
Total DX Dyslexia	166	88	9	142	15	5	86	9

symptoms. As such, it would be advantageous and scientifically significant if a broader sample of patients were examined to see whether the incidence of dyslexia, 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.[18]

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.[19]

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?[20]

Conclusions

This is a preliminary attempt to correlate color perception versus diagnosed symptoms of dyslexia. The Dyop color/contrast clinical validation was intended to clinically compare the qualitative Dyop duo color/contrast test as previously used anecdotally on an iPhone. The Clinical test results for diagnosed symptoms of dyslexia indicate an 80% to 90% association of color perception for the relative acuity endpoints for a Green-on-White versus a Blue-on-Black Dyop.

Recommendations

The methodology for this Dyop color/contrast screening test was based on the previous qualitative use on an iPhone of identical-diameter green-on-white and blue-on-black Dyops. That test forced the subject to choose only one of the spinning Dyops as still visible at a maximum distance. It also prevented the option of both Dyops being equally visible as to spin detection and the acuity endpoint.

The instances of equal acuity endpoints for green-on-white and blue-on-black Dyops indicate that the test was likely not properly understood by those subjects. The category where the L/M ratios' endpoints were equal was never observed in the initial anecdotal tests.

A quantitative clinical study is recommended which would determine an initial binocular acuity endpoint using a spinning black/white-on-gray Dyop as the acuity benchmark. That benchmark test would then be followed by use of a spinning green-on-white Dyop versus a spinning blue-on-black Dyop, alternating the color test sequences to determine their individual color acuity endpoints. That quantitative comparison should provide a more reliable comparison of color perception to symptoms of dyslexia.
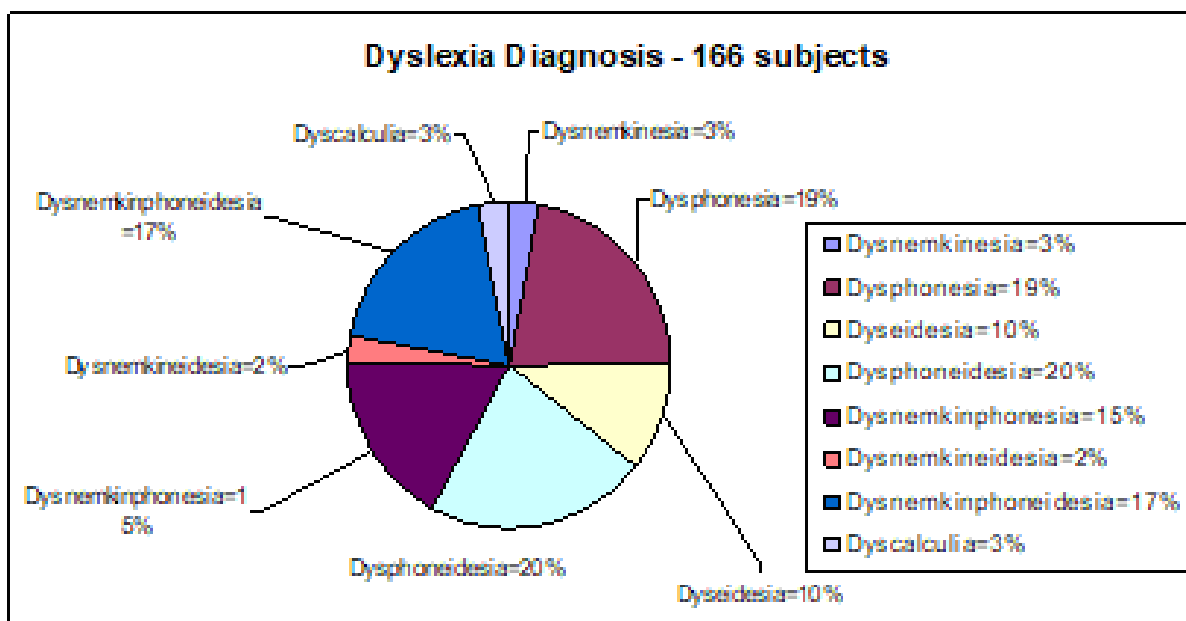
Figure 21. *Distribution of dyslexia categories for the 166 diagnosed dyslexia individuals in the study*
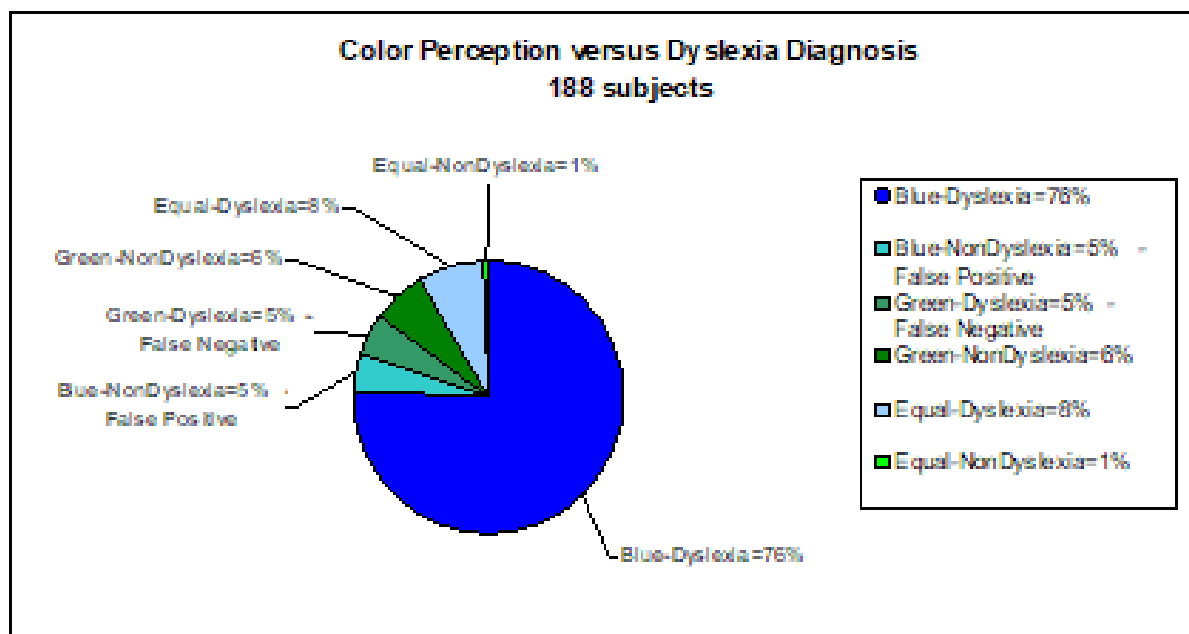

Figure 22. *Dyslexia diagnosis versus Dyop color/contrast perception for 188 subjects*

An enhanced quantitative study of color acuity utilizing the relative endpoints for red-on-gray, green-on-gray, and blue-on-gray Dyops should provide better validation of variances in color perception, as well as provide a better understanding for the mechanism of accommodation.

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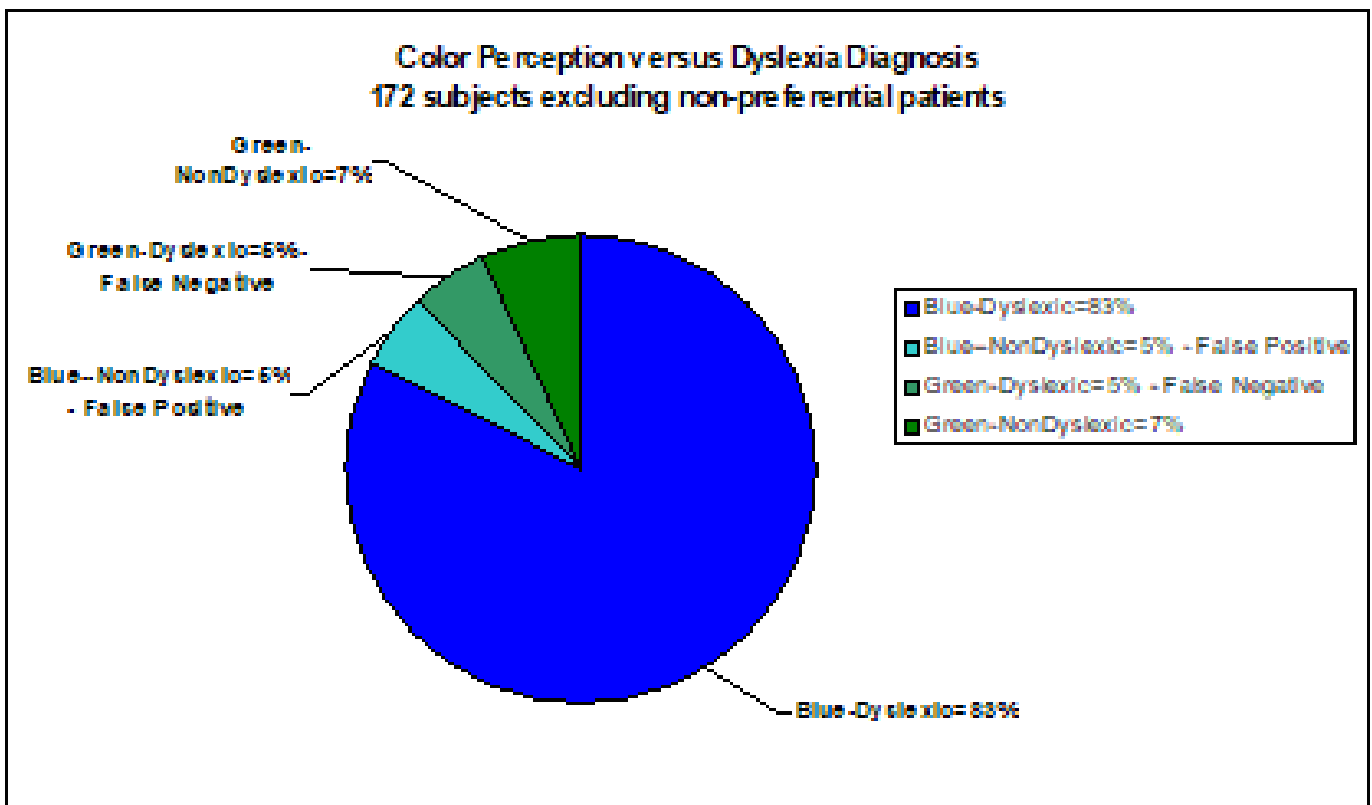
Figure 23. *Dyop color/contrast perception versus dyslexia diagnosis for 172 subjects that had a definitive color response*
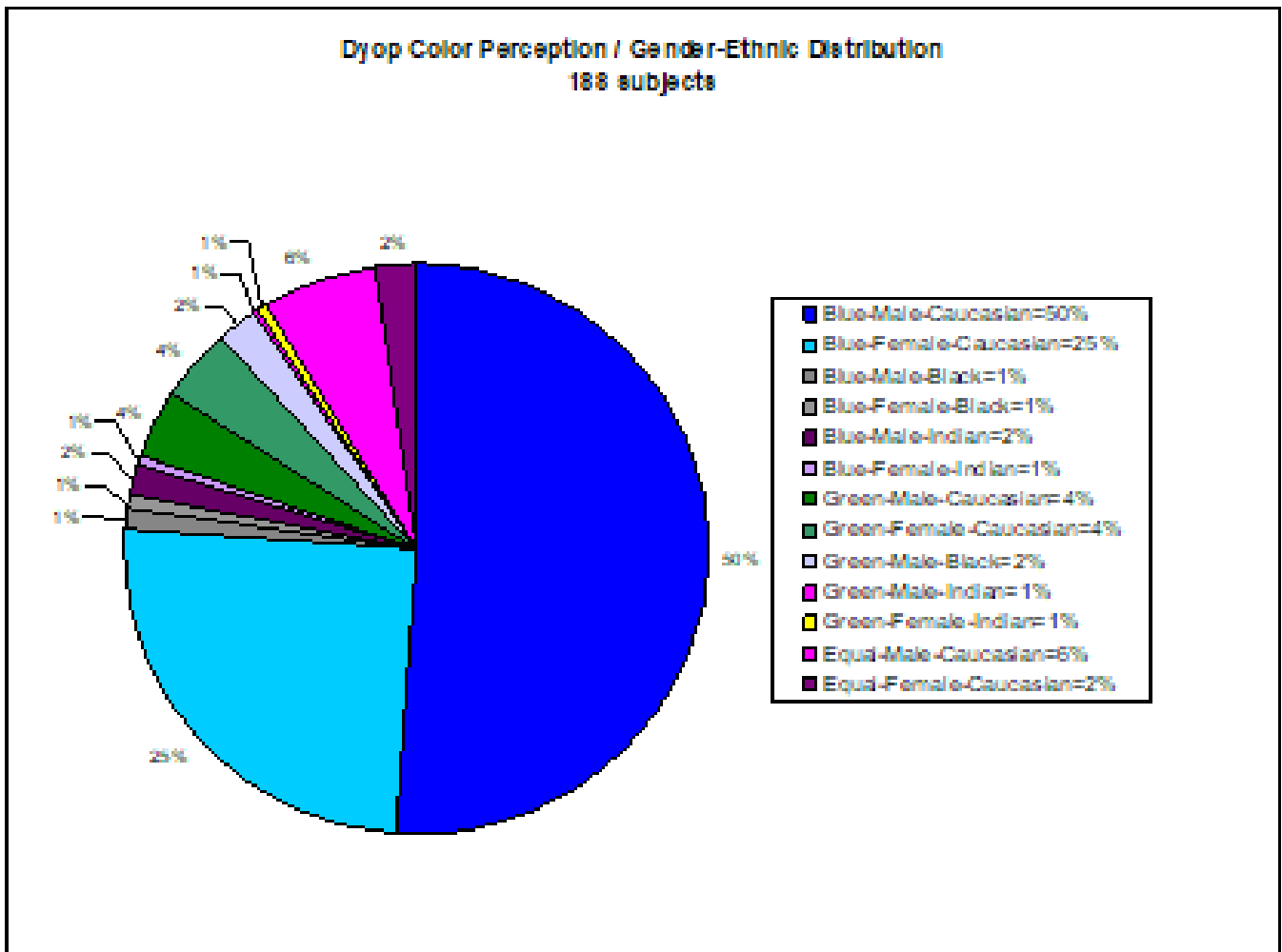

Figure 24. *Dyop color/contrast perception per gender and ethnic distribution for 188 subjects*

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