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UEC VISUAL ACUITY SYSTEM COMPARED TO THE VISUAL ACUITY MEASUREMENT STANDARD

I, Hin Cheung, hereby release this Paper as described above to Ferris State University with the understanding that it will be accessible to the general public. This release is required under the provisions of the Federal Privacy Act.

[redacted]
Doctoral Candidate

4/16/2014
Date

UEC VISUAL ACUITY SYSTEM COMPARED TO THE VISUAL ACUITY MEASUREMENT STANDARD

by

Hin Cheung

This paper is submitted in partial fulfillment of the requirements for the degree of

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UEC VISUAL ACUITY SYSTEM COMPARED TO THE VISUAL ACUITY MEASUREMENT STANDARD

by

Hin Cheung

Has been approved

May, 2013

APPROVED:

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ABSTRACT

Background: The purpose of this study is to compare the liquid-crystal display (LCD) screen method of visual acuity measurement using the Canela Visual Acuity System (CVAS) at the University Eye Center (UEC) with the Visual Acuity Measurement Standards (VAMS) set forth by the Visual Functions committee of the International Council of Ophthalmology. Specific inquiries in this study include: 1) optotype size progression, 2) consistency with Sloan letters, 3) number of letters presented per line and spacing between optotypes, 4) accuracy in presentation of varying contrast levels, and 5) effects of polarization at various viewing angles. *Methods:* The letter “E” and Landolt “C” will be isolated at each visual acuity line for comparison. The number of pixels on the LCD monitor for each letter and spacing between letters will be counted horizontally and vertically via a loop magnifier. The calculated visual acuity will be derived using the standard test distance employed in the clinic. A photometer will be used to measure the luminance under bright and dark conditions. *Results:* The calculated LogMAR deviates outside 5% tolerance between -0.50 to 0.30, or 20/6.3 to 20/40, for both letters “E” and Landolt “C”. The CVAS uses 16 letters, half are Sloan letters and half are not. Spacing between letters scale with letter size. Measured contrast levels fall outside 5% tolerance for letter contrast less than about 0.80, and a 5% difference exists between contrast levels in bright and dark conditions. Mean contrast also decreases as a function of viewing angle. *Conclusions:* The CVAS does not accurately display the stated visual acuity in some of the most commonly used sizes, including 20/20. In most cases, the displayed contrast level is much higher than stated. The CVAS requires further review to assess the reliability and accuracy in clinical use.

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CHAPTER 1

INTRODUCTION

The visual acuity measurement standards (VAMS) were established in 1984 by the Visual Functions Committee of the International Council of Ophthalmology (Enoch et al, 1984). Ophthalmologists and Optometrists were consulted to set the same guidelines across both professions as both measure visual acuity (VA) in their respective clinical settings. In addition, this also provides a guideline for manufacturers and designers of VA tests to allow repeatability and consistency in visual acuities.

The most common method of measuring acuity has long been the high contrast optotypes displayed from a projector. In recent years, newer technology has allowed the same optotypes to be displayed on Liquid Crystal Display (LCD) monitors with increased contrast and functionality. A LCD screen is composed of many pixels, which are the smallest elements of a two-dimensional grid that displays an image. These pixels are further divided into subpixels, which are responsible for the color elements of each pixel. In the LCD monitor, the subpixels are separated single-color regions, typically blue, red, and green (Dell Support, 2003). The LCD monitor also has polarizing filters in place which dictate the amount of light reaching each subpixel. The combination and variation of the intensity of the three subpixels is perceived by the brain as one blended color, thus creating the illusion of the variety of colors we see every day on television.

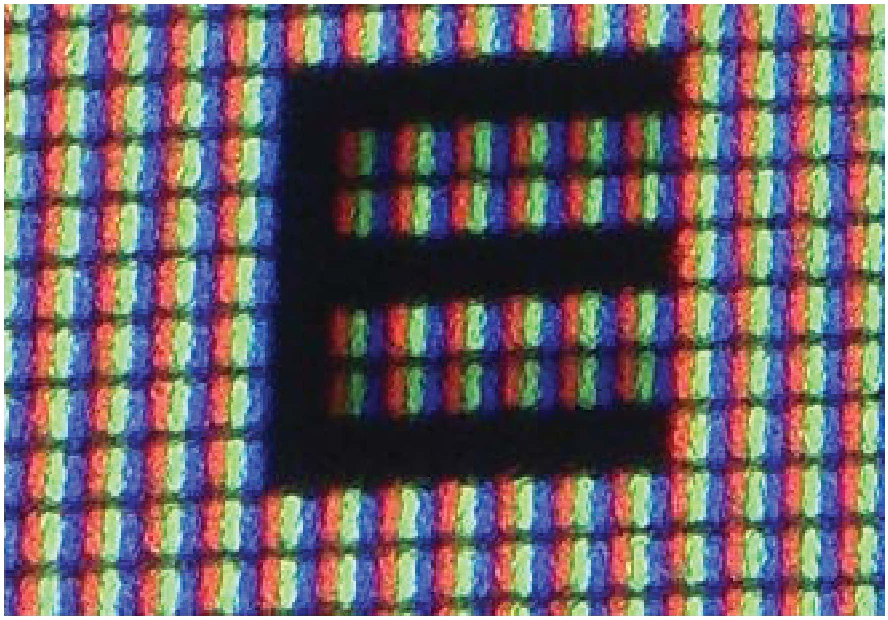

Illustration 1: Pixels and subpixels shown in a magnified 20/6.3 ‘E’. The subpixels that make up a single pixel can be seen as red, green, and blue. Anti-aliased pixels can also be seen in regions where the pixels appear shaded between each element of the “E”.

As mentioned before, the pixel is the smallest element of the display. It has a limited physical size. As such, it poses the question of whether the physical size of the pixel will interfere with an accurate display of a given optotype of a certain size. LCD monitors are also polarized, which will limit the viewing angle without compromising color, saturation, contrast, and brightness of the displayed image.

This study will investigate not only how a LCD monitor may affect the ability to display optotypes that fall within the acceptable range of accuracy, but also to evaluate the Canela Visual Acuity System 4 software (CVAS) used at the University Eye Center (UEC) against the standards put forth by the Visual Functions Committee of the International Council of Ophthalmology.

CHAPTER 2

METHODS

The letter “E” and the Landolt “C” were chosen to be the targets measured in this study. The size of the targets and the spacing between targets was measured by counting the number of pixels required to form each letter. This was performed with a Scale Lupe 10X magnifier, a product of the Lombart Instrument Company. The Lupe 10X magnifier also had a built in scale, allowing the pixel size to be measured. All measures of pixel counts were confined to a vertical letter “E” and “C” oriented rightward.

The number of letters presented in each line was counted from the smallest size, 20/6.3, to the largest size, 20/800. To determine the consistency with SLOAN letters, the letters used in this software was recorded by repeatedly refreshing the screen until all letters were sampled.

To assess the accuracy of displayed contrast levels, the luminance of the target and the background was measured in both bright and dark conditions at each contrast level perpendicular to the screen. A Konica Minolta LS-110 Luminance Meter was used to take four readings of each target and neighboring background, and these values were then averaged. Contrast measures were conducted on a 20/200 letter “E” optotype. Care was taken to choose a measurement area of the target and background near the center of the monitor to avoid the extraneous effects of luminance fluctuation encountered with increasing eccentricity from the center of the monitor.

To assess the effects of polarization of the LCD monitor and viewing angle on optotype luminance and contrast, the photometer was used to measure the luminance of the target and the background at various viewing angles. A vertical rightward oriented 20/200 letter “E” was used for all measures of contrast. Measurements were taken from 30º to 150º in increments of 10º; four readings were recorded and averaged. Each viewing angle was determined by using a protractor placed on the monitor followed by extending a taut string from the origin of the protractor along the respective angular scales imprinted on the protractor. This was used to mark a region on the floor 148.50cm from the monitor. The experimenter used this location when making the luminance measures. The origin of the protractor was placed so that it coincided with the geometric center of the monitor. Viewing angles below 30º and above 150º were not performed due to physical limitations of the room. Illustration 2 depicts how the measurements were taken.

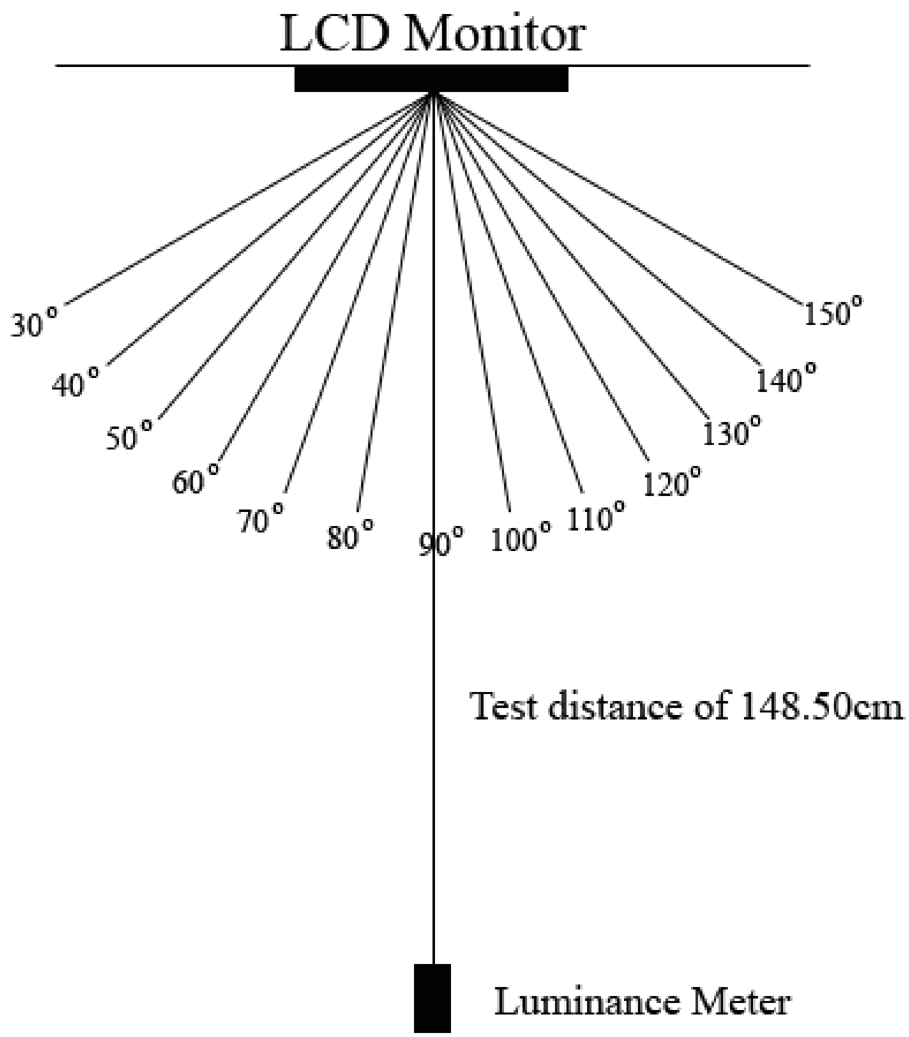

Illustration 2: Measurement of luminance at a test distance of 148.50cm using the Konica Minolta LS-110 Luminance meter at various viewing angles.

CHAPTER 3

RESULTS

Number of letters per line

The number of letters displayed at each optotype size varies from one to five letters. Letters displayed from 20/6.3 to 20/200 are shown in sets of five. 20/250 has four letters. 20/300 has three letters. 20/350 and 20/400 has two letters, and 20/800 has one letter.

Consistency with Sloan letters

The Sloan letters utilizes 10 of the 26 letters in the alphabet, they are: C, D, H, K, N, O, R, S, V, and Z (Enoch et al, 1984). The CVAS uses these 16 letters: A, B, C, D, E, F, G, H, L, N, O, P, S, T, V, and Z. The common letters between the Sloan set and the CVAS set are: C, D, H, N, O, S, V, and Z. The non-Sloan letters used are: A, B, E, F, G, L, P, and T.

Optotype size progression and spacing

A pixel is anti-aliased when the pixel is not solidly filled in; this is done to provide a smoother appearance to counteract the jagged nature of lines and curves made up of small squares. Each arm of the letter “E” as well as the space between each arm was counted. In table 1, the number of pixels that make up each arm, each space, as well as the number of anti-aliased components is shown. Refer to Illustration 3 for examples of anti-aliased elements. Using the Lupe 10X magnifier, each pixel was measured to be 0.25mm x 0.25mm. The calculated sizes for the letter “E” and Landolt “C” are summarized in Tables 1, 2, and 3 respectively.

VA 'E'	Black space	White space	Anti-alias
20/6.3	1,1,1	1,1	2
20/8	1,1,1	1,1	4
20/10	2,1,2	2,2	2
20/15	3,2,3	3,3	2
20/20	4,4,4	3,3	4
20/25	5,5,5	4,4	4
20/30	6,6,6	6,6	3
20/40	8,8,8	8,8	4
20/50	11,10,11	11,11	1
20/60	13,12,13	13,12	3
20/70	15,15,15	15,15	2
20/80	17,17,17	17,17	3
20/100	22,22,22	22,22	2

Table 1: The number of pixels that form each element of the letter “E”.

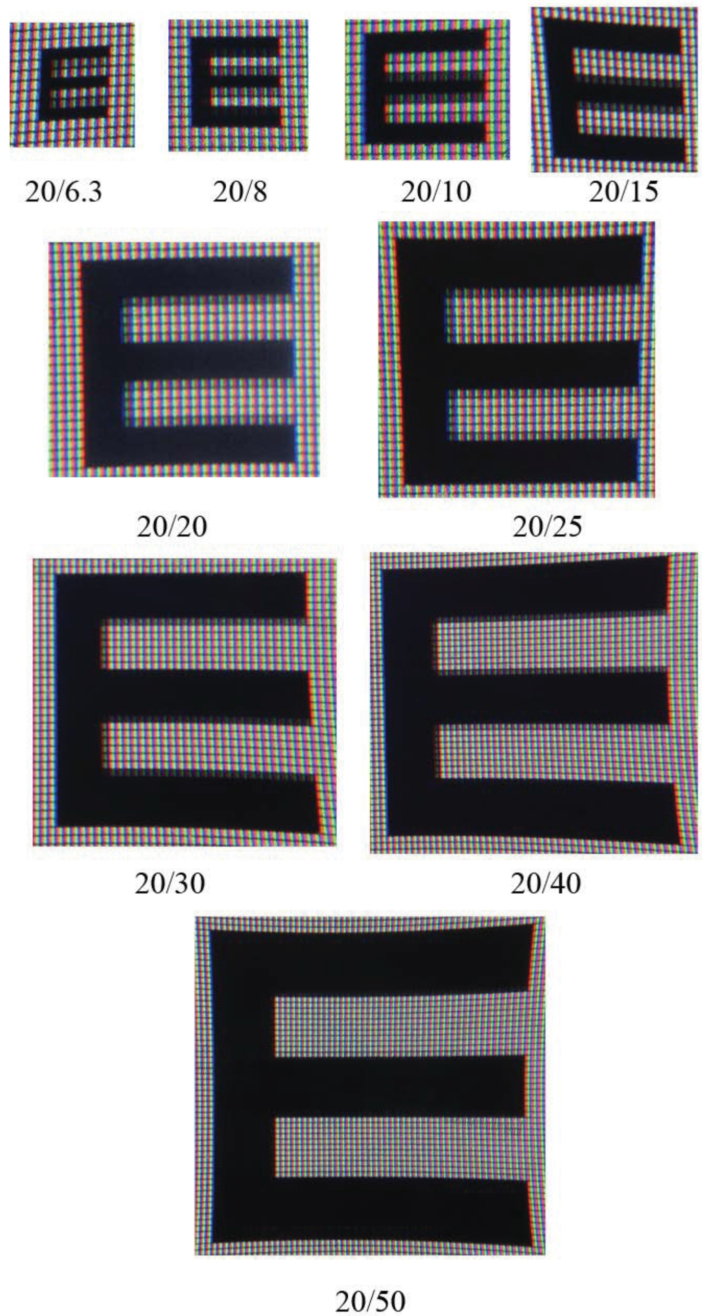

Illustration 3: Anti-aliased pixels (lighter gray pixels on the edges of the black limbs of the E) are seen in every target size. Here are examples between 20/6.3 and 20/50.

VA 'E'	H pixels	V pixels	Spacing	Horizontal (mm)	Vertical (mm)	Spacing (mm)
20/6.3	7	7	7	1.75	1.75	1.75
20/8	9	9	9	2.25	2.25	2.25
20/10	11	11	11	2.75	2.75	2.75
20/15	16	16	16	4.00	4.00	4.00
20/20	22	22	22	5.50	5.50	5.50
20/25	27	27	27	6.75	6.75	6.75
20/30	33	33	33	8.25	8.25	8.25
20/40	44	44	44	11.00	11.00	11.00
20/50	55	55	55	13.75	13.75	13.75
20/60	66	66	66	16.50	16.50	16.50
20/70	77	77	77	19.25	19.25	19.25
20/80	90	90	88	22.50	22.50	22.00
20/100	110	110		27.50	27.50	
20/150	165	165		41.25	41.25	
20/200	220	215		55.00	53.75	

Table 2: Measurements of the letter “E” at sizes 20/6.3 to 20/200, including number of horizontal and vertical pixels, number of pixels between targets, and their respective calculated length in mm. Spacing above 20/80 could not be quantified accurately due to physical limitations of the magnifier.

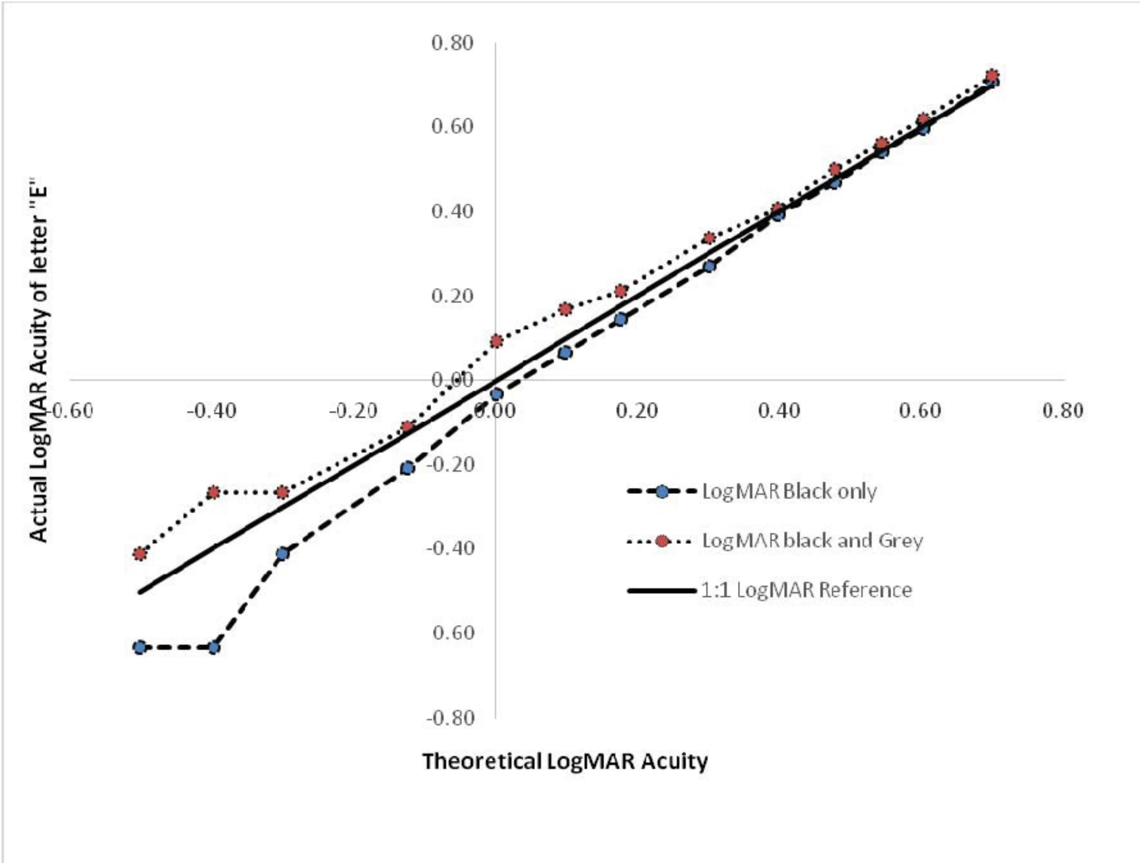

Figure 1: The actual logMAR acuity calculated from images of the letter "E" is plotted against the respective logMAR acuity as stated by the CVAS. "Black only" refers to stroke widths calculated from the average number of black pixels comprising each limb of the letter "E", and "Black and Grey" refer to stroke widths calculated from the average number of black and grey pixels comprising each limb of the letter "E". The greatest deviations from stated acuity values occur for smaller acuity levels and less so for LogMAR acuity sizes greater than 0.18, or 20/30.

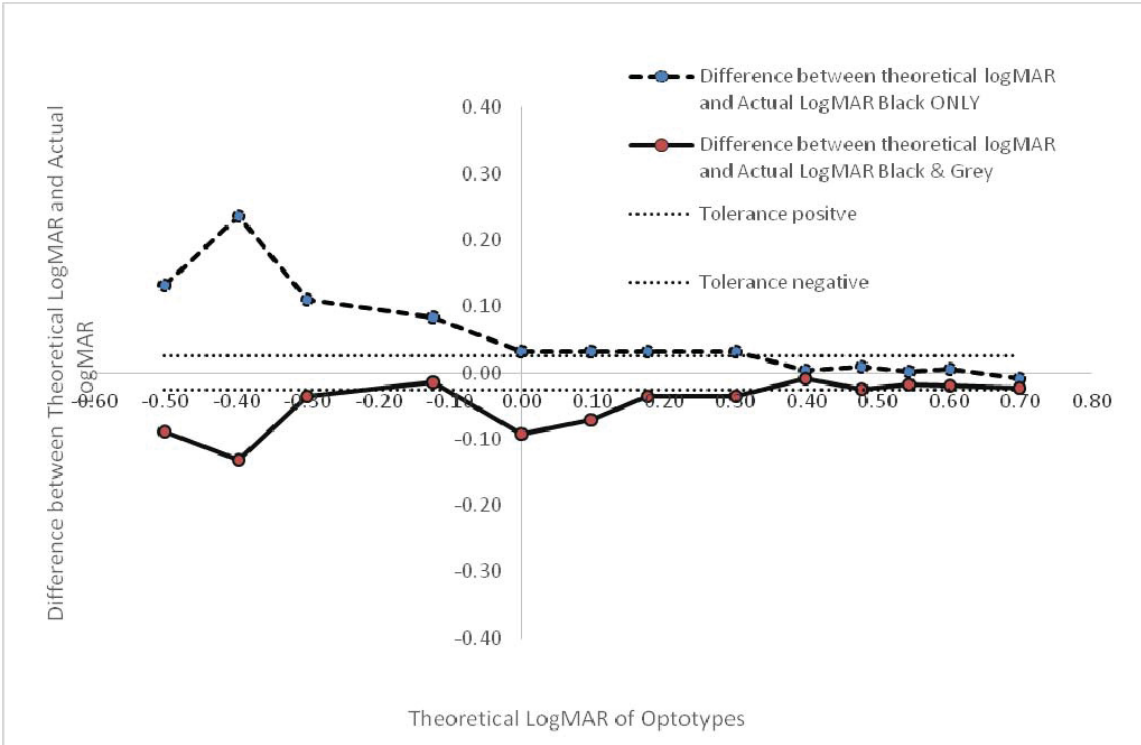

Figure 2: The difference between the theoretical acuity and the actual measured acuity of the letter "E" (expressed in log units) plotted against the theoretical logMAR acuity as stated by the CVAS. Fine dashed lines labeled "tolerance" depict 5% tolerance ranges for optotype angular sizes. For "Black only", tolernece is met at these LogMAR acuities: 0.40 to 0.70; or 20/50 to 20/100 respectively. For "Black and Grey", tolerance is met at these LogMAR acuities: -0.12 and 0.40 to 0.70; or 20/15 and 20/50 to 20/100 respectively.

VA 'C'	H pixels	V pixels	Spacing	Gap	Anti-alias	Horizontal (mm)	Vertical (mm)	Spacing (mm)	Gap (mm)	Gap/V
20/6.3	7	7	7	1	2	1.75	1.75	1.75	0.25	0.14
20/8	9	9	9	1	2	2.25	2.25	2.25	0.25	0.11
20/10	11	11	11	1	2	2.75	2.75	2.75	0.25	0.09
20/15	16	16	16	2	2	4.00	4.00	4.00	0.50	0.13
20/20	22	22	22	4	2	5.50	5.50	5.50	1.00	0.18
20/25	27	27	27	5	2	6.75	6.75	6.75	1.25	0.19
20/30	33	33	33	6	1	8.25	8.25	8.25	1.50	0.18
20/40	44	44	44	8	2	11.00	11.00	11.00	2.00	0.18
20/50	55	55	55	11	1	13.75	13.75	13.75	2.75	0.20
20/60	66	66	66	12	2	16.50	16.50	16.50	3.00	0.18
20/70	78	78	77	15	1	19.50	19.50	19.25	3.75	0.19
20/80	90	90	89	16	1	22.50	22.50	22.25	4.00	0.18
20/100	110	110	109	21	1	27.50	27.50	27.25	5.25	0.19
20/150	166	166		32	2	41.50	41.50	0.00	8.00	0.19
20/200				43	2				10.75	

Table 3: Measurements of the Landolt "C" at sizes 20/6.3 to 20/200, including number of horizontal and vertical pixels, number of pixels between targets, and their respective calculated length in mm. Gap/V represents the ratio between the size of the gap in the "C" compared to the size of the entire letter. This element is expected to be 20%, or one fifth of the optotype, similar to each arm of the letter "E". It can be seen that the 20/50 letter is the only optotype size that meets this criteria.

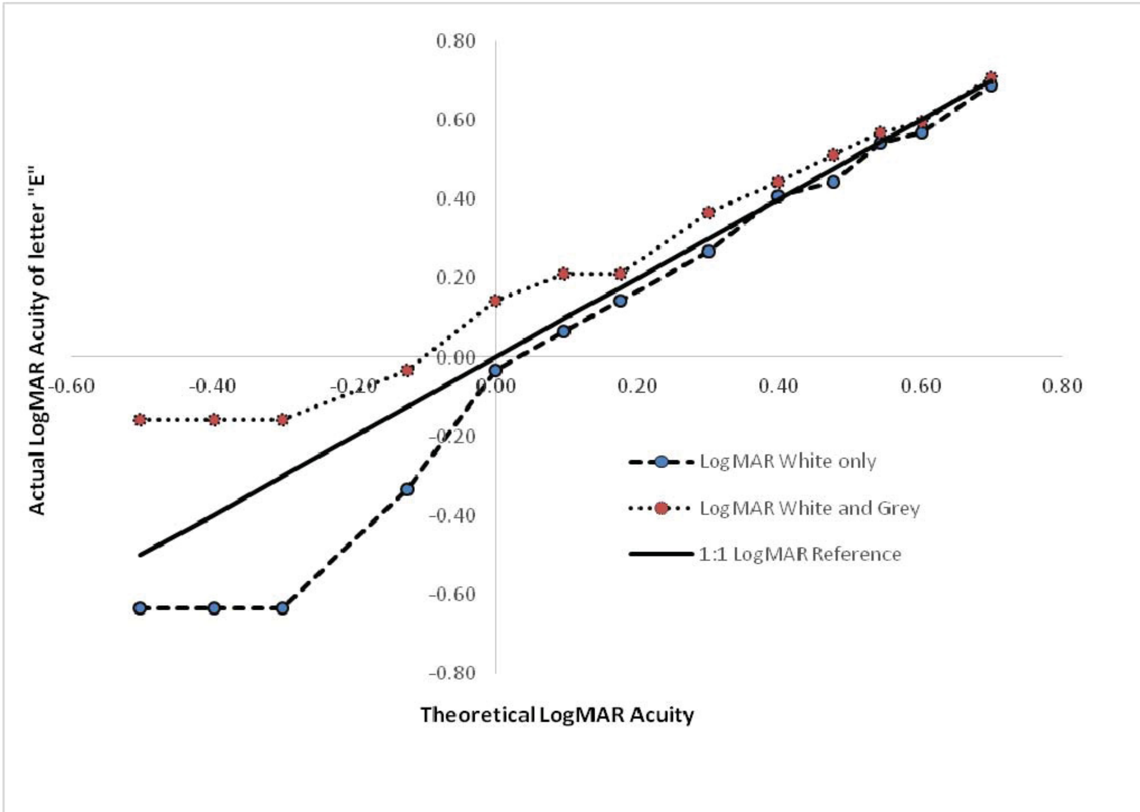

Figure 3: The actual logMAR acuity calculated from images of the Landolt "C" is plotted against the respective logMAR acuity as stated by the CVAS. "White only" refers to the number of white pixels creating the separation of the "C". "White and Grey" refers to the sum of white and grey pixels to make up the separation. The greatest deviations from stated acuity values occur for smaller acuity levels. Comparing the two, the "White only" closely resemble the 1:1 reference in LogMAR acuity of zero, or 20/20, and higher. The "White and Grey" begins to approximate the 1:1 reference at LogMAR acuity of 0.18, or 20/30, and higher.

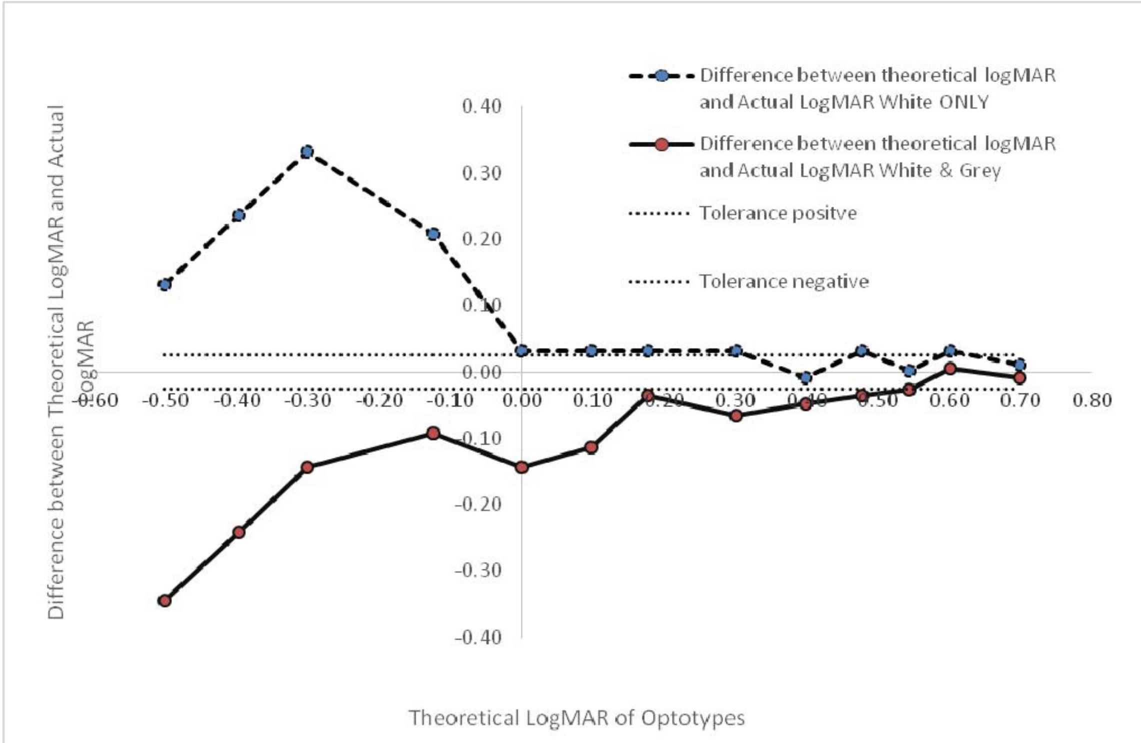

Figure 4: The difference between the theoretical acuity and the actual measured acuity of Landolt “C” (expressed in log units) plotted against the theoretical logMAR acuity as stated by the CVAS. Fine dashed lines labeled “tolerance” depict 5% tolerance ranges for optotype angular sizes. When considering the gap is made up of white pixels only, tolerance is met for the following LogMAR acuities: 0.40, 0.54, and 0.70; or 20/50, 20/70, and 20/100 respectively. If considering the gap is made up of both white and grey pixels, tolerance is met for the following LogMAR acuities: 0.60 and 0.70; or 20/80 and 20/100 respectively.

In addition, VAMS dictates that acuity levels should change by a constant LogMAR value, typically 0.1 log units is used. Table 4 below is the calculated LogMAR values of both letters "E" and Landolt "C".

	Calculated LogMAR of "E"		Calculated LogMAR of "C"	
VA	Black only	Black and Grey	White only	White and Grey
20/6.3	-0.63	-0.41	-0.63	-0.16
20/8	-0.63	-0.27	-0.63	-0.16
20/10	-0.41	-0.27	-0.63	-0.16
20/15	-0.21	-0.11	-0.33	-0.03
20/20	-0.03	0.09	-0.03	0.14
20/25	0.06	0.17	0.06	0.21
20/30	0.14	0.21	0.14	0.21
20/40	0.27	0.34	0.27	0.37
20/50	0.39	0.41	0.41	0.45
20/60	0.47	0.50	0.45	0.51
20/70	0.53	0.56	0.54	0.57
20/80	0.60	0.62	0.57	0.60
20/100	0.71	0.72	0.69	0.71

Table 4: Calculated LogMAR of both letters "E" and Landolt "C". It can be seen that the acuity level is not increasing at a constant LogMAR value.

Accuracy of various Optotype contrast levels

The luminance of the targets and the background in both bright and dark conditions are summarized in Table 5.

Contrast (%)	AVG LT OFF (cd/m^2)	AVG LB OFF (cd/m^2)	AVG LT ON (cd/m^2)	AVG LB ON (cd/m^2)
100	0.50	156.35	4.82	160.00
90	1.98	156.58	6.41	161.05
80	5.10	155.50	9.49	158.98
70	11.42	156.25	15.78	160.18
60	20.22	156.38	24.58	160.73
50	32.58	155.95	36.90	160.68
40	47.23	155.95	51.99	161.20
30	66.80	154.20	71.44	160.20
20	89.71	155.30	94.94	159.50
10	120.45	155.40	125.35	161.00
5	135.05	156.45	139.25	161.23

Table 5: The averages of four readings of the luminance of the target (AVG LT) and luminance of the background (AVG LB) in two lighting conditions: all room lights on or all room lights off.

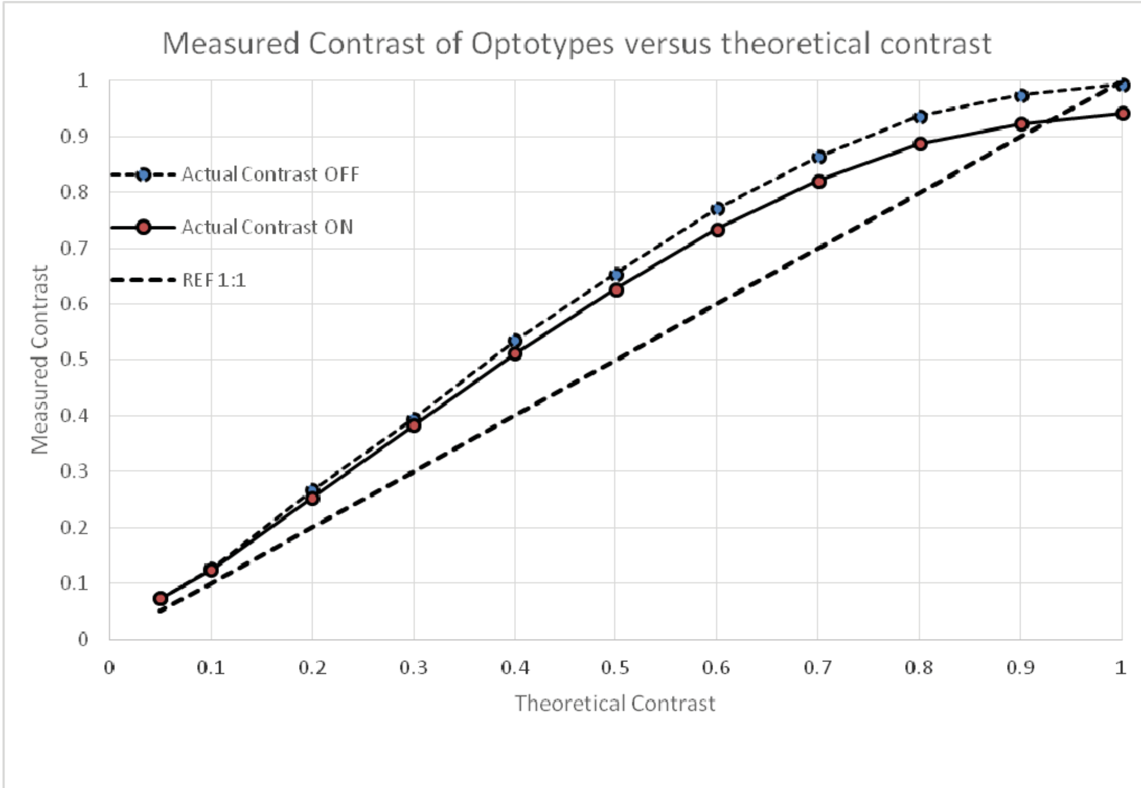

Figure 5: The mean contrast (+/- 95%CI) of a 20/200 letter "E" optotype plotted against the contrast as stated by the CVAS for lights OFF (blue, dashed) and lights ON (red, solid). Dashed line labeled "REF" depicts a 1:1 reference line of direct proportionality.

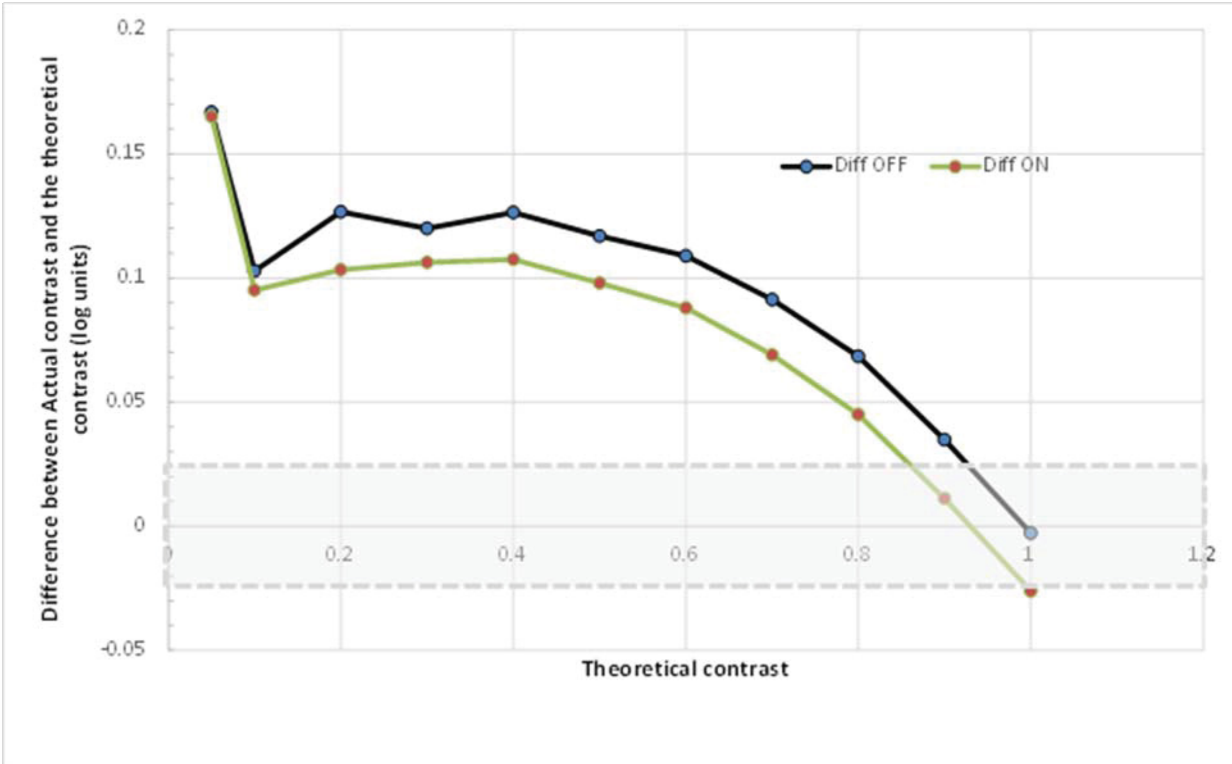

Figure 6: The difference between measured contrast of a 20/200 letter E optotype (expressed in log units) plotted against the contrast as stated by the CVAS for lights OFF (blue) and lights ON (red). The grey region represents a 5% error range. There are significant departures (>5%) from linearity of optotype contrast specifically for contrast levels lower than about 0.80, with maximal differences occurring for low optotype contrasts. Two way ANOVA showed a significant difference in contrasts between light condition after allowing for the effects of differences in contrast levels ($F(1,21) = 23.34$, $p < 0.001$).

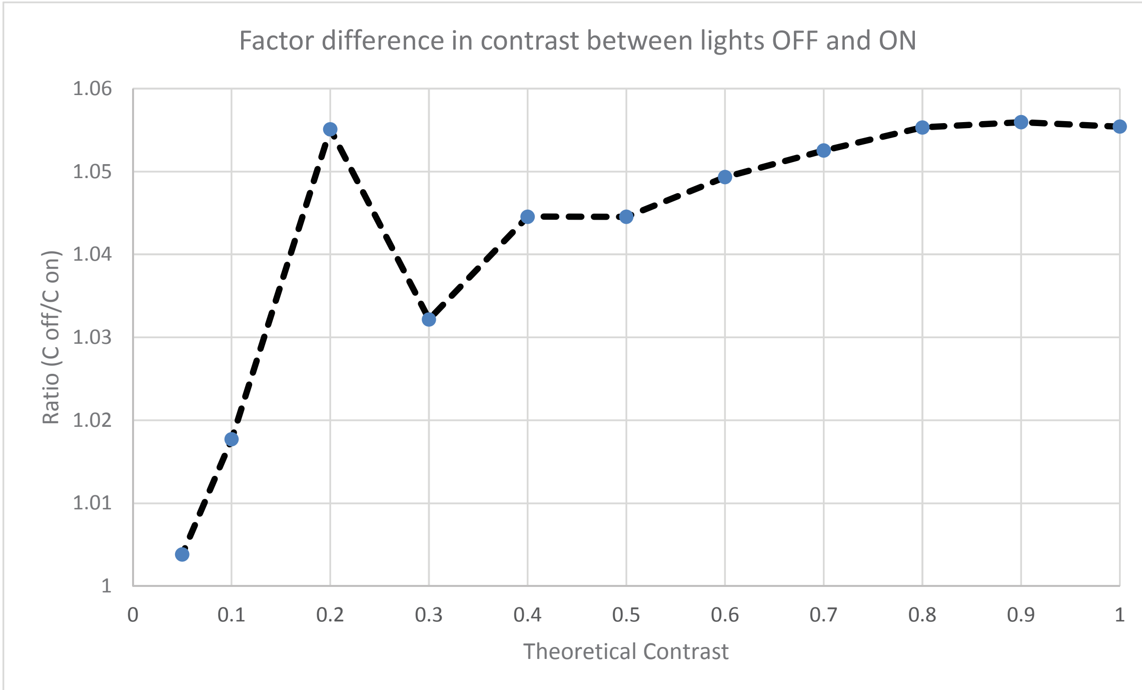

Figure 7A: The factor difference in actual contrast of the Optotype between Lights OFF and ON for various contrast levels as stated by the CVAS. It is evident that beyond approximately 20% contrast, there is approximately a constant 5% difference between the OFF and ON condition

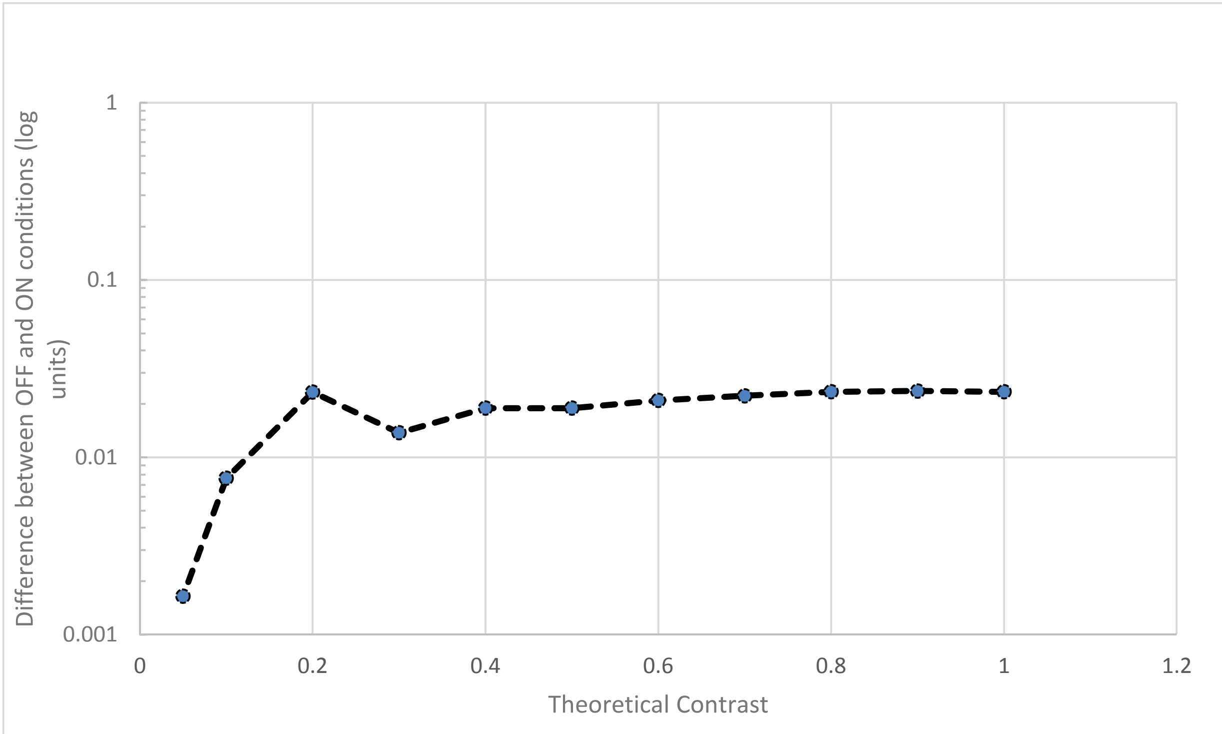

Figure 7B: The same data from 7A re-plotted as log unit differences. It is evident that beyond approximately 20% contrast, there is approximately 0.025 log unit difference in optotype contrast between the two viewing conditions, which corresponds to the constant 5% difference noted above in 7A.

According to the VAMS, the recommended test luminance in the United States of America is 85 cd/m^2. Referring back to Table 4, the average luminance of the background is consistently above 154 cd/m^2 in dark conditions, and above 158 cd/m^2 in bright conditions. The background luminance under both conditions meets the standards, and in fact is well above the minimum requirement in the United States of 85 cd/m^2.

Effects of polarization at varying viewing angles

The luminance of the target and background is measured at various viewing angles to assess the effects of polarization on the visibility of the targets. Table 4 below summarizes these findings.

Degrees	**AVG LT (cd/m^2)**	**AVG LB (cd/m^2)**
30	4.49	85.51
40	4.16	103.65
50	3.80	115.48
60	3.26	134.43
70	4.13	151.43
80	4.59	158.60
90	4.11	160.03
100	5.41	156.33
110	5.29	147.08
120	4.95	135.40
130	4.52	116.78
140	4.60	90.89
150	4.82	63.46

Table 6: The averages of four readings of the luminance of the target (AVG LT) and the background (AVG LB) in bright conditions were measured at viewing angles between 30 degrees and 150 degrees at 10 degree increments.

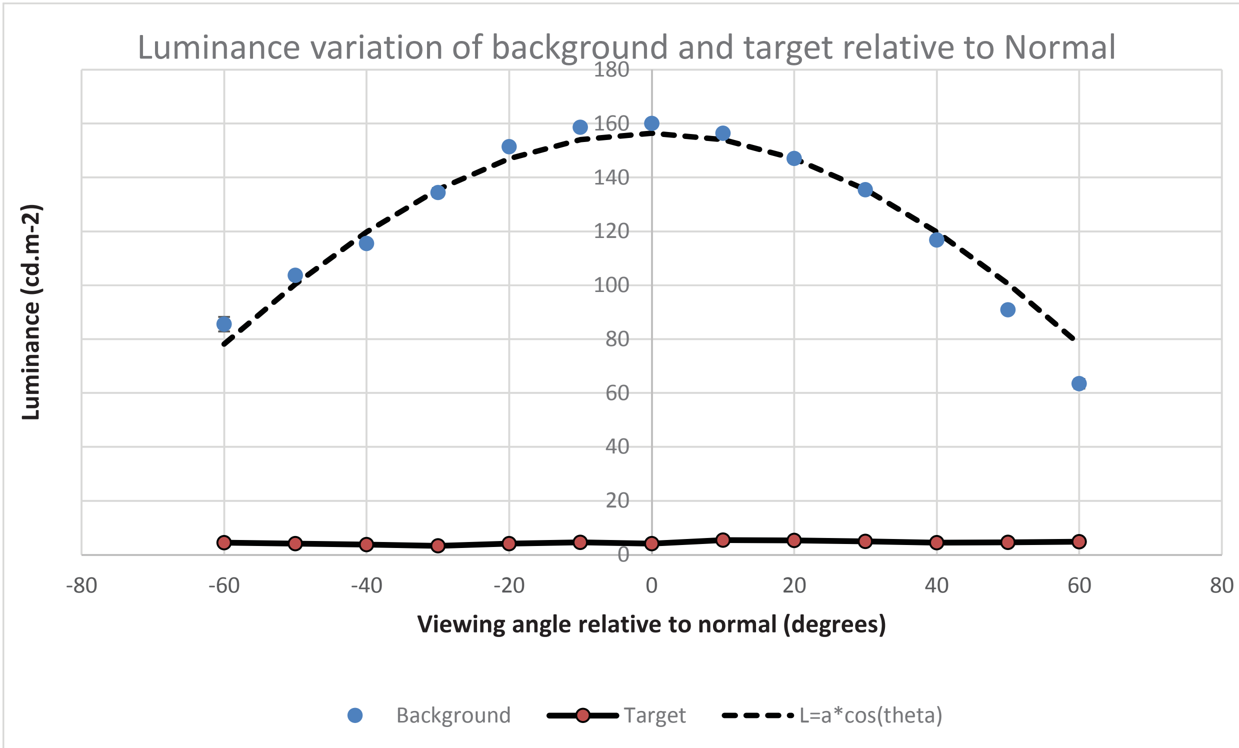

Figure 8A: The mean (+/- 95%CI) variation in luminance (cd/m^2) of the background and the target of a high contrast (1.0) "E" viewed under bright conditions (~160 cd/m^2) is plotted as a function of viewing angle relative to a viewing position that is perpendicular to the screen. Luminance of the background varies with the cosine of the viewing angle relative to the normal position, while luminance of the target is relatively constant with viewing angle.

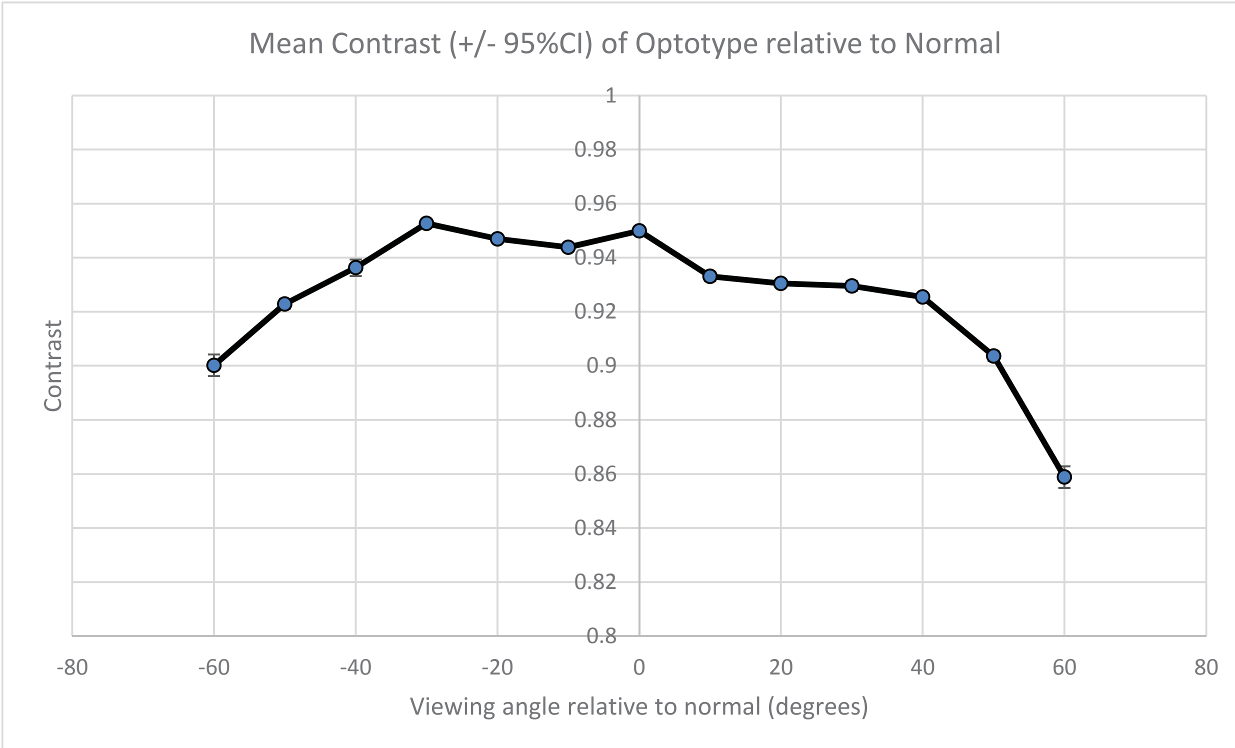

Figure 8B: The mean calculated contrast (+/-95%CI) of the same target as a function of viewing angle. The mean contrast decreases as the viewing angle increases. The VAMS dictates the letter contrast be 0.80 or higher for reliable and stable measures of acuity. In this case, the mean contrast is above 0.80 and meets the requirement at all viewing angles measured.

CHAPTER 4

DISCUSSION

Visual acuity is the first and often most important piece of clinical finding for a clinician to assess the visual capabilities of a patient. It aids the clinician during refraction to achieve an appropriate and comfortable correction for the patient. It is used to determine visual aids for patients with specific visual demands or with low vision. It is a vital test for screenings to rule out abnormalities. It can also be used to monitor the effects or progression of diseases and treatments. While VA is important to all the above and more, it has to be interpreted with all ocular findings as a whole and not in isolation. With a wide variety of assessments that require and depend on VA, it is important that the VA measurement is accurate and repeatable across the profession (Enoch et al, 1984).

The LCD screen is the physical limit as to how many letters can be displayed at once. With increasing optotype size, less room is available while maintaining equal and appropriate spacing between each optotype to avoid crowding. Five letters are shown between 20/6.3 and 20/200; four letters for 20/250; three letters for 20/300; two letters for 20/350 and 20/400; and one letter for 20/800. The spacing is consistent to the size of the letter at every measured target size. This is appropriate to ensure proper spacing between letters to avoid crowding.

The Sloan letters is one of the most commonly used letter set in clinical testing and research. Historically, Sloan letters were chosen to "provide nearly equivalent percent correct values for visual acuity" (Alexander et al, 1996). In other words, when used as a group, Sloan letters on average have equivalent legibility. However, it has been found that the individual Sloan letters with curved features, such as C or O, have a lower legibility than those with straight edges, such as Z (Alexander et al, 1996). The Sloan letters used by CVAS are C, D, H, N, O, S, V, and Z. The non-Sloan letters used are A, B, E, F, G, L, P, and T. This finding raises concern that the average legibility of optotypes comprising each acuity line may vary from one line to the next, and perhaps between multiple presentations of the same line. Therefore, further research is needed to assess whether the relative legibility of the combined use of Sloan and non-Sloan letters in the CVAS are similar.

The ability for the LCD monitor and CVAS software to present optotype of accurate size is critical. Our data reveals that the calculated LogMAR of the letter "E" approximates that of the theoretical LogMAR stated by the CVAS in LogMAR acuities 0.40 to 0.70, or 20/50 to 20/100, in both "Black only" and "Black and Grey" groups. Optotype displayed at a smaller size is outside the 5% tolerance range, with the exception of LogMAR -0.12, or 20/15, in the "Black and Grey" group.

Comparing this with the data from Figure 3 and Figure 4, it reveals that the Landolt "C" has even less optotype sizes within tolerance. A comparison shown in Figure 4 shows a significant difference between how we determine the size of the separation, especially for small optotypes. In the case that the separation consists only of white pixels, LogMAR acuities 0.40, 0.54, and 0.70, or 20/50, 20/70, and 20/100 respectively, are within tolerance. When both white and grey pixels are considered as the gap, only LogMAR acuities of 0.60 and 0.70, or 20/80 and 20/100, are within tolerance.

The troubling finding is that both letter “E” and Landolt “C” fall outside of the 5% tolerance range when presented in sizes -0.50 to 0.30, or 20/6.3 to 20/40, regardless of how we determine the size of the critical element in the letter. Both letters have shown to exceed the 5% tolerance in some of the most commonly used optotype sizes, most importantly LogMAR of zero, or 20/20. These findings suggest the CVAS does not accurately display the stated VA within tolerance levels, specifically when optotypes are presented using the anti-aliased mode. It must be highlighted that these measures were confined to the letter “E” and Landolt “C” optotypes because of the relative ease of counting pixels in these optotypes. Notwithstanding this, the result raises significant concern whether such inaccuracies also exist within the alphabet-based optotype that are used most commonly to measure acuity, especially given the complexities of letter features comprising the alphabet-based optotypes.

Most visual acuities are performed under high contrast conditions. It is important to remember that measuring contrast sensitivity (CS) is also clinically relevant. CS is not only a sensitive indicator of disease or disease progression, but has strong associations to everyday tasks; from reading to driving to facial recognition (Arditi, 2005). In the past, most measurements of CS were a grating CS, but letter CS has become more practical in clinical settings (Arditi, 2005). In Figure 5, the lowest and highest measured contrast levels most closely resemble the theoretical value, but the stated contrast levels between

30% and 80% have a measured contrast of 10% or higher than the theoretical value under bright conditions. This deviation is exaggerated in dark conditions. In Figure 6, it reveals that the difference between the actual contrast and the theoretical contrast exceed a 5% error, especially for contrast levels lower than 0.80. A two way ANOVA showed a significant difference in contrasts between light conditions after allowing for the effects of differences in contrast levels ($F(1,21) = 23.34$, $p < 0.001$).

Comparing the difference of contrast levels presented by CVAS in bright and dark conditions, there is a constant 5% difference beyond 20% contrast. This corresponds to approximately 0.025 log unit difference between the two viewing conditions. Although the optotype contrast varied between the two lighting conditions, the peak contrast is still well above 0.80 in both conditions, which is the lower limit of acceptable optotype contrast proposed by the VAMS.

Lastly, the use of a LCD screen poses the challenge of polarization and its possible effects on VA measures under different viewing angles. In Figure 8A, it reveals that the luminance of the background varies with the cosine of the viewing angle; as one move away from the normal to view the target, the luminance of the background decreases. However, the luminance of the target remains relatively constant in all viewing angles, specifically for the optotypes used in this study. Similarly in Figure 8B, it shows the mean contrast of the optotype decreasing with increasing viewing angle away from the normal. In other words, as one deviates away from the normal, with the luminance of the target remaining constant and the luminance of the background decreasing, the mean contrast of the letter will also decrease and become more difficult to distinguish. While

CS can be useful in monitoring disease progression, it must be an accurate measurement. If the display does not accurately produce the stated contrast level, if the contrast changes under different lighting conditions, or if the display or the patient is at an angle, the CS measured may be inaccurate. Further research in this area will be required to determine the proper lighting conditions and the tolerance of the viewing angle to obtaining accurate measurements.

With the constant advances in technology, one can expect to see the increasing use of electronic devices for measuring VA. One study investigated the reliability of VA measurements using Sloan letters displayed by desktop computers and iPads (Raumivboonsuk et al, 2012). Their results suggest that reliable visual acuities can be measured, and more importantly, repeatable, with these electronic devices. With the rise of electronic options to measure VA, it is crucial to understand their capabilities before employing them and relying on them in clinical practice.

In conclusion, there are critical areas of the CVAS investigated that exceed tolerance dictated by the VAMS. The LogMAR acuities of both “E” and Landolt “C” exceed 5% tolerance in the most commonly used visual acuities. The CVAS letter size does not change by a constant LogMAR value. When assessing the ability for the CVAS to present low contrast targets, measured contrast levels fall outside 5% tolerance for letter contrast less than 0.80; in fact, many of the low contrast targets were 10% or higher than its theoretical contrast level. Although a 5% constant difference was found between bright and dark conditions, the luminance of the background met the minimum requirement of 85 cd/m^2 within the United States. The mean contrast of the optotype decreases with increasing viewing angle, but remains above 0.80 required by the VAMS. Half of the CVAS letter set is comprised of non-Sloan letters, further investigation is required to assess the legibility of the combined use of Sloan and non-Sloan letters. The number of letters per line is appropriate; and the spacing between letters scale consistently with letter size. Overall, further evaluation on the CVAS is required to assess its ability to produce meaningful clinical data.

Criteria	Notes	Meet VAMS?
Optotype size progression	Progress by a constant LogMAR value	✗
Accuracy of optotype size displayed	Within 5 % tolerance	✗
Consistency with SLOAN letters	C, D, H, K, N, O, R, S, V, and Z.	✗
Spacing between optotypes	Scales to size of optotype	✓
Background luminance	Above 85 cd/m^2 (United States)	✓
Mean letter contrast	Above 0.80	✓
Accuracy of contrast display	Within 5% tolerance	✗

Table 7: Summary of results

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