Original Article

Contrast sensitivity assessment using the Mars letter contrast sensitivity test

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ABSTRACT

Background: Contrast sensitivity (CS) represents an individual's ability to detect differences in luminance between two areas and is an essential component of vision. Various studies have evaluated the relevance of different charts to assess CS in ophthalmology practice. We evaluated the CS of healthy individuals using the Mars letter CS chart.

Methods: In this hospital-based cross-sectional study, we consecutively recruited healthy individuals older than 18 years with unremarkable ocular examinations who attended the general outpatient clinic at Benue State University Teaching Hospital, Makurdi, Nigeria, between March 2021 and July 2021. Each participant was allocated to one of five groups with 10-year age intervals and 1:1 male-to-female ratios. All participants underwent a detailed ophthalmic examination. We tested visual fields using the 24-2 program on a Humphrey visual field analyzer with appropriate refractive correction. Monocular testing of CS with appropriate spectacle correction was performed using a Mars letter CS chart. The tribe, age, and sex of each individual, along with the best-corrected visual acuity (BCVA), intraocular pressure, mesopic pupil size, cup-to-disc ratio (C/D ratio), and mean deviation (MD) of the visual field for each eye were recorded.

Results: A total of 100 eyes of 50 patients with a mean (standard deviation [SD]) age of 44.6 (12.8) years and a 1:1 male-to-female ratio were enrolled. The mean (SD) CS score for the 100 included eyes was 1.67 (0.09) log units. The mean (SD) CS score was comparable between sex groups and tribes (both $P > 0.05$) yet differed significantly between age groups ($P < 0.001$). We found a significant good inverse correlation between CS score and age ($r = -0.60$; $P = 0.001$), a low inverse correlation with BCVA ($r = -0.29$; $P < 0.003$), and a low direct correlation with C/D ratio ($r = +0.23$; $P = 0.023$); however, we observed no significant correlation with tribe ($r = +0.07$; $P = 0.053$), sex ($r = +0.16$; $P = 0.123$), IOP ($r = +0.07$; $P = 0.481$), mesopic pupil size ($r = -0.02$; $P = 0.861$), and mean deviation of visual field ($r = +0.02$; $P = 0.873$).

Conclusions: We observed a progressive decline in the mean CS score in healthy eyes with each decade of increase in age. Our findings are similar to those of previous studies and could be used as reference values for the healthy population among various age groups. However, further studies with larger sample sizes are necessary to encourage clinicians to incorporate CS into routine examinations. Further studies must compare these normative values with those of disease conditions to further understand the clinical application of the CS test.

KEYWORDS

healthy participant, visual contrast sensitivity, visual acuities, visual field test, pupils, optic nerves, age group, genotypic sex

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How to cite this article: Okwori OP, Chaha K, Lawan A, Eze UA. Contrast sensitivity assessment using the Mars letter contrast sensitivity test. Med Hypothesis Discov Innov Optom. 2024 Spring; 5(1): 10-17. DOI: https://doi.org/10.51329/mehdioptometry192

Received: 29 March 2024; Accepted: 30 April 2024

INTRODUCTION

Contrast sensitivity (CS) represents an individual's ability to detect a difference in luminance between two areas. *Spatial* CS is the ability to detect a difference in luminance between two adjacent areas, whereas *Temporal* CS is the ability to detect a difference in luminance between areas that appear sequentially in time [1, 2]. Contrast can be quantified using various formulas, including the Weber formula, which is used when the background luminance remains constant, and the Michelson formula, which is used when the light and dark components both change [2, 3]. CS tests are categorized into two groups: those using letters and those using gratings. Each method has various advantages and drawbacks; however, as the most important aspects of a test, both must accurately differentiate healthy from diseased eyes and provide reproducible results [2].

Although many CS tests with gratings have been developed, most have moderate to low test-retest reproducibility [4-6]. Common spatial CS charts include Arden plates, Cambridge gratings, and the VectorVision CSV-1000 (VectorVision, Greenville, OH, USA). The letter-based CS tests, such as the Pelli-Robson chart, Regan charts, and Mars Test, often exhibit better reproducibility; however, they can be influenced by literacy and chart fading. The different categories of CS charts can also be administered using computer-based testing. For instance, the Spaeth or Richman Contrast Sensitivity Test uses a grating chart to examine both central and peripheral CS [2, 7]. Numerous studies have assessed CS in normal individuals [8-16].

The Pelli-Robson CS chart is the most widely used instrument in research [17]. However, similar to other charts, it has technical problems, such as uneven illumination, print fading, surface reflections, and the need to recognize letters [2, 18]. The Mars Letter CS Test is similar in design to the Pelli-Robson chart, as they both use Sloan letters. The contrast decreases by 0.04 log unit for adjacent letters in the Mars Test but not for triplets in the Pelli-Robson chart. The range of contrast tested is 91–1.2%. The Mars chart is smaller than the Pelli-Robson chart and is used for near testing, specifically 0.5 m. The test ends when the patient incorrectly identifies two consecutive letters [2]. Dougherty et al. [19] evaluated the repeatability of the results of the Mars Test and how they align with those of the Pelli-Robson chart in normal- and low-vision individuals. The Mars Test showed good repeatability and high agreement with the Pelli-Robson chart [19]. This indicates that the Mars chart can be used interchangeably with the Pelli-Robson chart.

Using the relatively inexpensive, portable, and simple Mars Letter CS chart [20], we aimed to generate normative data for our environment as a basis for further clinical studies and to assess ocular and demographic factors that may correlate with monocular CS values.

METHODS

This hospital-based cross-sectional study consecutively recruited healthy participants attending the general outpatient clinic at the Benue State University Teaching Hospital, Makurdi, Nigeria, from March 2021 to July 2021. Ethical approval was obtained from the Research and Ethics Committee of Benue University Teaching Hospital Makurdi (BSUTH/CMAC/HREC/101/2020/011). All eligible participants provided written informed consent prior to enrollment.

To determine participants' eligibility, their medical histories were obtained, and a full ocular examination was performed. Inclusion criteria were: participants older than 18 years old; those that provided full informed consent; those without medical conditions that could affect ocular structures or likely preclude the acquisition of valid data, such as cognitive impairment, Parkinson's disease, Alzheimer's disease, other neurological or musculoskeletal disease, or diabetes mellitus; and those with best-corrected visual acuity (BCVA) > 6/9, normal visual field testing, intraocular pressure (IOP) < 21 mmHg, and a cup-to-disc ratio (C/D ratio) < 0.5.

We excluded those with any ocular pathology or complaints; extreme refractive errors such as myopia ≥ -5.0 diopters (D), hyperopia ≥ + 5.0 D, or astigmatism ≥ 3.0 diopter cylinders; or clinically significant lenticular opacity according to the Lens Opacity Classification System III (LOCS III) [21]. The exclusion criteria for lenticular opacity were nuclear color/opalescence > NC2 and NO2, respectively; cortical cataract > C2; and posterior subcapsular cataract ≥ P1.

Eligible participants were recruited Monday through Friday from the general outpatient ophthalmology clinics at the hospital. We included all individuals who were present during the study period and met the inclusion criteria. They participated in routine examinations and were not given prior knowledge of the study to avoid bias in participant selection. Participants were categorized into five age groups with equal male-to-female ratios: 20–29 years old, 30–39 years old, 40–49 years old, 50–59 years old, and 60–69 years old.

Distance visual acuity was measured using a Snellen chart placed 6 m away under bright illumination. Each eye was tested separately, with the other eye covered. The last line accurately read on the chart was recorded as the visual acuity for that eye. For participants with visual acuity worse than 6/6, objective refraction was performed using streak retinoscopy (WelchAllyn®; REF18240;Skaneateles Falls, NY, USA) and subjectively refined. The BCVA of each eye was converted to the logarithm of the minimum angle of resolution (logMAR) notation. Unaided and aided near vision were evaluated for each eye using a near vision chart at 33 cm (British "N" reading chart, recorded as the British "N" score) in a well-lit room.

Anterior segments were examined under a slit lamp (LED Slit Lamp AIA-11; Appasamy Associates, Tamil Nadu, India). IOP was measured using a Goldmann applanation tonometer (Tonometer AATM; Appasamy Associates, Chennai, Tamil Nadu, India) after applying 0.5% tetracaine hydrochloride anesthetic eye drops and fluorescein dye. Both pupils were dilated using 1% tropicamide or 2.5% phenylephrine; the posterior segments were examined under a slit lamp using a + 78 D lens (Volk Optical Inc., Mentor, OH, USA); and the vertical C/D ratio was recorded for each eye [22].

Based on the effect of pharmacological mydriasis, all participants had a second follow-up visit to complete the CS and visual field examinations. Visual fields were plotted [23] using the 24-2 program on the Humphrey Visual Field Analyzer (Humphrey C 24-2 SITA-Standard Visual Field; Tomey AP-250; version 7.4.0S; Kowa Co., Tokyo, Japan, and Mayo Co., Aichi, Japan) with the appropriate refractive correction in place.

The individual's BCVA was used during the CS test. The Mars Letter CS chart (Mars Perceptrix, Chappaqua, NY) [17, 19, 24] was used to test CS. Monocular testing was twice performed on each eye, and the best result was selected. Each participant received a detailed explanation of the test procedure prior. Testing was conducted in a room with fluorescent lighting (ambient indoor illumination) and without daylight to minimize glare and reflections and ensure uniform testing conditions. Monocular testing was conducted with the participant's appropriate spectacle correction for both near and distance. Two Mars chart forms were supplied, each with a different letter sequence. Each form has eight rows of letters, with six Sloan letters per row; chart 1 was used for the right eye, whereas chart 2 was for the left eye. The letters were constantly sized, and contrast was reduced across and down the chart and the log unit scale.

The Mars chart was placed on a reading stand at 50 cm; thus, the subtended angle was 2°, the change in contrast between successive letters was 0.04 log units (10%), and the log units ranged from 0.04 to 1.92 [17, 19, 24]. To score the test, a value of 0.04 log unit was given per correctly named letter, and testing ended when the individual misidentified two consecutive letters. Thus, the final contrast score was calculated by multiplying 0.04 by the number of letters identified correctly.

Data were analyzed using SPSS Statistics for Windows (version 23.0; IBM Corp., Armonk, NY, USA). The means and standard deviations (SDs) and the frequencies (percentages) were presented for continuous and categorical variables, respectively. We assessed normality and homogeneity of variances using the Shapiro-Wilk test and Levene's test, respectively. We used the independent *t*-test to compare two independent groups. To compare more than two groups, we used one-way analysis of variance (ANOVA), followed by Tukey's honestly significant difference (HSD) post-hoc test if ANOVA yielded significant differences. We used Pearson's product-moment correlation to determine the relationship between mean CS values and individual demographic and clinical characteristics. A P-value < 0.05 indicated statistically significant differences.

RESULTS

A total of 100 eyes of 50 individuals with a mean (SD) age of 44.6 (12.8) years old and a male-to-female ratio of 1:1 were assessed. The mean (SD) Mars CS score was 1.67 (0.09) log units (Table 1). Table 1 summarizes the clinical characteristics of study participants.

We observed no statistically significant differences in mean CS among the different tribes or between the two sexes (both $P > 0.05$); however, mean CS differed significantly among age groups ($P < 0.001$) (Table 2). Pairwise analysis revealed that the mean (SD) CS was significantly less in the 50–59-year age group than in the 20–29-year ($P < 0.001$) and 30–39-year ($P = 0.001$) age groups. Similarly, the mean (SD) CS was significantly less in the 60–69-year age group than in the 20–29-year ($P < 0.001$), 30–39-year ($P < 0.001$), and 40–49-year ($P = 0.002$) age groups (Table 3). The mean CS score progressively declined with each decade's increase in age, as shown in Figure 1.

CS score had a significant good inverse correlation with age (r = - 0.60; $P = 0.001$), a low inverse correlation with BCVA (r = - 0.29; $P < 0.003$), and a low direct correlation with C/D ratio (r = + 0.23; $P = 0.023$). However, no significant correlations between CS score and tribe (r = + 0.07; $P = 0.053$), sex (r = + 0.16; $P = 0.123$), IOP (r = + 0.07; $P = 0.481$), mesopic pupil size (r = - 0.02; $P = 0.861$), and mean deviation of visual field (r = + 0.02; $P = 0.873$) were observed.

Table 1. Clinical characteristics of study participants

Variable	Mean ± SD (n = 100)
BCVA (logMAR)	- 0.05 ± 0.07
IOP (mmHg)	14.38 ± 3.55
Mesopic pupil size(mm)	5.12 ± 1.00
C/D ratio	0.33 ± 0.09
MD (decibel)	- 0.40 ± 0.33
CS (log units)	1.67 ± 0.09

Abbreviations: SD, standard deviation; n, number of eyes; BCVA, best-corrected visual acuity; logMAR, logarithm of the minimum angle of resolution; IOP, intraocular pressure; mmHg, millimeter of mercury; mm, millimeters; C/D ratio, cup-to-disc ratio; MD, mean deviation obtained in the visual field using Humphrey 24-2 Swedish Interactive Threshold Algorithm Standard perimeter; CS, contrast sensitivity measured using the Mars Letter Contrast Sensitivity chart.

Table 2. Contrast sensitivity values measured using the Mars Letter chart among tribes, sexes, and age groups

Variable		CS (log units), Mean ± SD (Range)	*P*-value
Tribe	Tiv, n = 52 eyes	1.65 ± 0.10	0.053
	Igede, n = 6 eyes	1.68 ± 0.10	
	Idoma, n = 16 eyes	1.69 ± 0.06	
	Igbo, n = 14 eyes	1.72 ± 0.07	
	Others, n = 12 eyes	1.70 ± 0.07	
Sex	Men, n = 50 eyes	1.66 ± 0.08	0.110
	Women, n = 50 eyes	1.69 ± 0.10	
Age group	20–29 years, n = 20 eyes	1.74 ± 0.06 (1.64 to 1.84)	**< 0.001**
	30–39 years, n = 20 eyes	1.73 ± 0.05 (1.68 to 1.80	
	40–49 years, n = 20 eyes	1.68 ± 0.06 (1.60 to 1.84)	
	50–59 years, n = 20 eyes	1.63 ± 0.04 (1.56 to 1.68)	
	60–69 years, n = 20 eyes	1.59 ± 0.12 (1.44 to 1.80)	

Abbreviations: CS, contrast sensitivity measured using the Mars Letter Contrast Sensitivity chart; SD, standard deviation; n, number of eyes. Note: *P*-value < 0.05 is shown in bold.

Table 3. Pairwise comparisons of age groups using post-hoc Tukey's test

Paired age groups	*P*-value for pair-wise comparison
20–29 y vs 30–39 y	0.992
20–29 y vs 40–49 y	0.119
20–29 y vs 50–59 y	**< 0.001**
20–29 y vs 60–69 y	**< 0.001**
30–39 y vs 40–49 y	0.284
30–39 y vs 50–59 y	**0.001**
30–39 y vs 60–69 y	**< 0.001**
40–49 y vs 50–59 y	0.243
40–49 y vs 60–69 y	**0.002**
50–59 y vs 60–69 y	0.353

Abbreviations: y, years; vs, versus. Note: *P*-values < 0.05 are shown in bold.

DISCUSSION

We found comparable CS values among tribes and sex groups. However, the mean CS score progressively declined in healthy eyes as age increased. Among the clinical and demographic characteristics of participants, age had a significant good inverse correlation with the mean CS and BCVA had a low inverse correlation with the mean CS, whereas C/D ratio had a low direct correlation. We found no statistically significant correlation between CS values and IOP, mesopic pupil size, mean deviation in visual field, or sex.

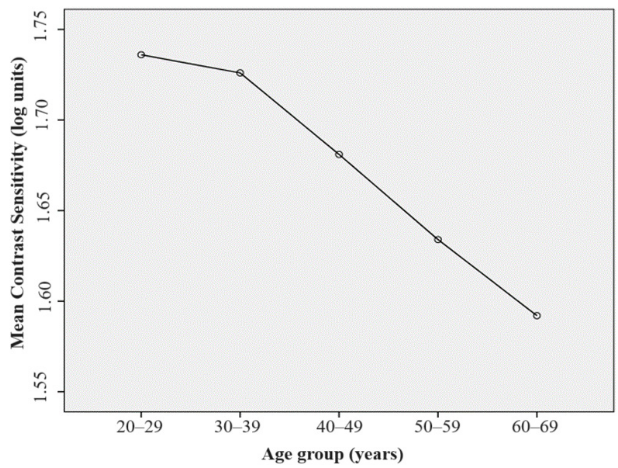

Figure 1. Mean contrast sensitivity plot by age groups.

CS provides useful information about an individual's visual function, which affects real-world performance and may be useful for monitoring ophthalmic treatment and detecting disease [17, 25]. Many have debated the superiority of the CS score over high-contrast visual acuity measured using Snellen or other equivalent charts. Ginsburg believed that CS [26] is a more relevant tool in assessing visual function; however, since different charts have varying sensitivities and specificities, their roles in the clinical setting remain poorly understood [26, 27]. In addition, although there is little consensus regarding the best method to test CS [28], most studies have shown high levels of agreement between the various CS charts [17, 28]. Therefore, we chose the Mars Letter CS chart, which is a relatively new, inexpensive, portable, and simple tool [20], to assess the CS of healthy individuals in our population, to generate normative data, and to identify clinical and demographic characteristics that may affect mean CS values. Relatively few studies have used the Mars chart to provide normative mean CS values that we can compare to our measured values [17, 19].

In general, our results align with those of other studies that also used the Mars Letter CS chart. For instance, the mean (SD) CS for healthy individuals in our study was 1.67 (0.09) log units, which is similar to the value obtained by Haymes et al. (1.62 [0.06] log units) [17]. Compared with our results, the mean (SD) CS value obtained by Dougherty et al. using the Mars chart [19] was higher (1.72 [0.07] log units). The reason for this difference may be difficult to determine; however, one possible reason may be because they used habitual refraction [19] rather than BCVA, which was used in our study. Furthermore, they accepted "C" and "O" miscalls [19], whereas we accepted no miscalls. Studies with larger sample sizes may provide more insight into this disparity.

We sought to determine the range of CS values for each age group in the current study. The range was 1.64–1.84 log units for participants aged 20–29 years old and 1.44–1.80 log units for those aged 60–69 years old. Haymes et al. [17] suggested that a 25-year-old person's upper and lower limits of normal Mars CS values were approximately 1.72 and 1.56 log units, respectively, whereas a 60-year-old person's upper and lower limits were approximately 1.68 and 1.52 log units, respectively [17].

We found a statistically significant good correlation between increasing age and decreasing CS scores in healthy individuals ($r = -0.60$, $P = 0.001$), which is similar to the results of previous studies that used various CS charts [17, 29]. One study [30] found that CS decreased in scotopic conditions and at high spatial frequencies with advancing age. However, no effect of age on CS was observed in photopic conditions. Li et al. [31] demonstrated that age is the main factor associated with CS. Some studies, however, have indicated that CS does not decrease appreciably with advancing age [32, 33]. Hohberger et al. [34] found a significant correlation between age and CS [34]. Meanwhile, our study observed differences between age groups through further comparison of their mean CS values; however, some were statistically insignificant. Establishing the normal ranges of CS within each age group may be preferable to using an absolute mean value; however, further studies with larger sample sizes are required to ascertain these normative values.

Evidence has suggested that the macular pigments, photoreceptors, and neural paths are affected by age; particularly, the number of rods decreases more than that of cones [35-37]. These changes may explain the decreased CS [17, 29, 30] and visual acuity [38] and the prolonged dark adaptation [38, 39] with advancing age. However, the effect of lens abnormalities on CS in this population could be a factor [40]. This study attempted to reduce the influence of cataracts on CS measurements by excluding patients who had clinically significant lenticular opacities according to the LOCS III classification [21].

We observed a low but statistically significant inverse correlation ($r = -0.29$; $P < 0.003$) between CS values and BCVA, aligning with the finding of Xiong et al. [40], who found a weak inverse relationship ($r = -0.34$, $P < 0.001$) between visual acuity and CS in their normal control group. In their study strength of correlation was higher in individuals with coexisting ocular entities such as cataract ($r = -0.43$, $P < 0.001$), age-related macular degeneration ($r = -0.68$, $P < 0.001$), glaucoma ($r = -0.50$, $P < 0.001$), and retinitis pigmentosa ($r = -0.78$, $P < 0.001$) [40]. Future studies should use the Mars Letter CS chart to compare the mean CS in normal eyes and in those with known ocular disease to increase the clinical applicability of this CS test to ocular diseases and to promote its use among eye care practitioners for assessing and monitoring ocular diseases potentially affecting CS.

We found no statistically significant correlation between CS values and IOP, mesopic pupil size, mean deviation in visual field, or sex. Anderson and Stainer also found no correlation between CS and IOP reduction in patients with ocular hypertension [41]. Pupillary size has been speculated to reduce CS by diffraction with a miotic pupil and by spherical aberration with a dilated pupil [42]. However, Karatepe et al. [30] found no relationship between CS and pupillary size in photopic conditions. By contrast, a significant increase in CS at high spatial frequencies was detected in mesopic conditions associated with a larger pupil diameter [30].

To assess sex-related differences, our participants were sex-matched, with equal numbers of men and women in each age group. No significant sex-related differences were observed within or between age groups. Solberg et al. found that CS was not affected by sex [43]. However, Li et al. [33] found a statistically significant difference in contrast visual acuity in the low-contrast range between male and female individuals [33]. Abramov et al. also reported sex differences in spatio-temporal CS using grating patterns [44]. Additionally, van Alphen et al. [45] found statistically significant differences between male and female mice in their study. The reasons for these differences were not elucidated; however, van Alphen et al. [45] still recommend sex matching of participants for vision-related studies.

We recorded the mean CS values of normal individuals in different age groups, sexes, and tribes and investigated possible demographic and clinical characteristics associated with the mean CS values. This age-wise normative data could serve as reference values for individuals with normal visual acuity. However, this study is limited by its small sample size, the absence of a comparison group with known ocular entities that could affect CS, and the restriction to a single center. Further longitudinal studies could verify our findings and provide robust evidence concerning changes in CS parameters across age groups. Furthermore, large-scale studies including both normal individuals and those with known ocular entities could provide better perspectives regarding CS in different ocular pathologies.

CONCLUSIONS

We observed a progressive decline in mean CS scores in healthy eyes as age increased by a decade. Our findings are similar to those of previous studies and could be used as reference values for healthy individuals among various age groups. However, we found no significant correlation between CS values and IOP, mesopic pupil size, mean deviation in visual field, or sex. Further studies must compare these normative values with those of disease conditions to further understand the clinical application of CS tests. We hope that our findings will stimulate further research with larger sample sizes and encourage clinicians to incorporate CS testing into their routine examinations, mainly in resource-poor settings. However, literacy issues and the varied ocular and demographic factors that can influence CS measurement may hinder its use.

ETHICAL DECLARATIONS

Ethical approval: Ethical approval was obtained from the Research and Ethics Committee of Benue University Teaching Hospital Makurdi (BSUTH/CMAC/HREC/101/2020/011). All eligible participants provided written informed consent prior to enrollment.
Conflict of interests: None.

FUNDING

None.

ACKNOWLEDGMENT

None.

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