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Original research

Comparison of two methods for measuring contrast sensitivity in anisometropic amblyopia

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Abstract

Purpose: This study aimed to evaluate two psychophysical contrast sensitivity testing methods in amblyopic patients.
Methods: Thirty-three adults with anisometropic amblyopia participated in this study. Psychophysical contrast sensitivity was measured for both amblyopic and fellow eyes of the participants at 1, 3, and 5 cycles per degree (cpd) spatial frequencies by Freiburg visual acuity and contrast test (FrACT) and Metrovision contrast sensitivity test, which employ sine-wave gratings for measurement of contrast sensitivity. We evaluated the correlation between the two tests and used Bland−Altman analysis to measure the agreement between the two methods.
Results: Except for 1 cpd in amblyopic eyes, FrACT showed significantly higher contrast sensitivity measurements than Metrovision at all spatial frequencies both in normal and amblyopic eyes ($P < 0.01$). The difference between the two methods increased with an increase in spatial frequency. There was a significant correlation between the two tests at most of the spatial frequencies. While the difference between the results of the two tests increased with an increase in contrast sensitivity in amblyopic eyes, we found an inter-test agreement in normal eyes.
Conclusion: Although both FrACT and Metrovision employ sine-wave gratings to measure contrast sensitivity, there are some differences between them, and their results cannot be used interchangeably.
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Keywords: Contrast sensitivity; Sine-wave grating; Amblyopia; Psychophysics

Introduction

Contrast sensitivity represents a series of visual information processes that occur in the spatial vision. Thus, it can be used to assess the functional integrity of the visual system.[1] Because of the high clinical value of contrast sensitivity findings in diagnosis and assessment of treatment process, several procedures have been introduced for its measurement. For this reason, investigators have made efforts to find reliable, simple, and quick methods for contrast sensitivity measurement.[2] Since different psychophysical tests designed for contrast sensitivity measurement employ different stimuli, they may involve different parts of the visual system. Thus, use of different methods for evaluation of contrast sensitivity in amblyopic eyes can lead to clarification of various aspects of the condition and identification of the affected areas in the visual system.

Previous studies comparing different contrast sensitivity measurement techniques have shown contradictory results. Hong et al. compared two psychophysical tests which both

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employed sine-wave grating stimulations. However, he found a poor correlation between them.[3] Neargardner et al.[4] compared four different contrast sensitivity testing methods and found a correlation between FrACT and Pelli-Robson, and also between Vistech and Regan at some spatial frequencies and contrast levels. Buhren et al. found significant differences between the results of three tests with different stimulating methods (Pelli-Robson, FF-CATS, and FACT) under different light conditions and concluded that the results of these tests were not interchangeable.[5]

In the current study, we evaluated the correlation between the results of two psychophysical contrast sensitivity testing methods (FrACT and Metrovision) in the amblyopic and fellow eye of patients with anisometropic amblyopia. To our knowledge, these two methods have not been compared in amblyopic and normal eyes.

Methods

Thirty-three anisometropic amblyopia patients including 19 male and 14 female aged 16–35 years were included in this study. The ocular health of the participants was confirmed through examinations including ophthalmoscopy, external ocular examination, ocular motility, and pupillary light reflex. Each patient was asked for general health and use of any drugs. The patients with any central nervous system (CNS) disease or those who used drugs affecting the CNS were excluded from the study. Visual acuity was measured with Nidek system Chart SC-1600 (Nidek Co., Aichi, Japan). The minimum and maximum acceptable best corrected visual acuity for inclusion was 0.4 and 0.1 logMAR, respectively. Patients in this range of visual acuity are considered amblyopic while the resolution is not diminished severely. Thus, contrast sensitivity may not be affected significantly by decreased resolution. The examinations were done monocularly on non-dilated pupils with best refractive correction. Since low ambient light shifts the contrast sensitivity function (CSF) towards lower spatial frequencies,[6] the tests were conducted under photopic conditions. Moreover, it has been reported that photopic conditions are less sensitive to optical changes than mesopic conditions.[5] We explained the tests to the participants. Since any previous experience of psychophysical tests may affect the results, we asked the participants whether they ever did these tests. None of them had done the tests before. To prevent any learning and/or fatigue effect, all measurements were performed in a randomized order with a 5-min rest between the tests. Measurements for all patients were performed between 9 and 12 a.m. and by the same clinician to avoid subjective error.

Metrovision contrast sensitivity test

Monpack One® (Metrovision, Pérenchies, France) is originally an electrophysiology testing system that employs vertical sine-wave gratings for measurement of psychophysical contrast sensitivity at various spatial frequencies. Each grating is first presented with very low contrast, and then the contrast is progressively increased. The patient presses a button when he or she detects the grating bars from a plain screen. Since FrACT grating contrast sensitivity test were carried out at 1, 3, and 5 cycles per degree (cpd) spatial frequencies, the values of these spatial frequencies were extracted from the CSF of the Metrovision test. The area under logarithm of contrast sensitivity function (AULCSF) was also calculated for spatial frequencies of 1–5 cpd.

FrACT grating contrast sensitivity test

Freiburg visual acuity and contrast test (FrACT, version 3.7.1b, <michaelbach.de/fract) is a computer program that can measure psychophysical contrast sensitivity using sine-wave gratings among other functions. FrACT employs a four-alternative forced choice (4-AFC) and Best Parameter Estimation by Sequential Testing (Best PEST) algorithm to estimate the threshold for grating contrast sensitivity. This algorithm displays a series of stimuli and calculates each following stimulus and ultimately the threshold value from the responses given by the observer to the stimuli.[5] Gratings were displayed in a 2-degree field in horizontal, vertical, and two diagonal directions at 1, 3, and 5 cpd spatial frequencies. Each stimulus was displayed for 3 s to increase coordination with Metrovision contrast sensitivity test. Metrovision increases the stimulus contrast rapidly, and the observer does not have much time to recognize gratings at each contrast level.

Contrast sensitivity is the inverse of contrast threshold. As a standard in visual sciences, the results of contrast sensitivity measurements are reported in a logarithmic scale, due to the fact that sensory systems respond logarithmically to changes in sensory stimulations.[7] Furthermore, logarithmic conversion places contrast sensitivity measurements in a linear scale which is more convenient for statistical analysis.[8] Consequently, the results obtained from both tests were converted to logarithm of contrast sensitivity (log CS) for analysis. Statistical analyses were performed using SPSS version 19.0 (IBM SPSS, Armonk, NY, USA). Non-parametric Spearman's rho test was used for evaluation of correlation between two tests (non-parametric analysis has been done based on non-normal distribution of the data). *P* value less than 0.05 were considered significant. Bland–Altman analysis was applied to measure the agreement between the two tests, and 95% limits of agreement [mean difference ± 1.96 standard deviation (SD)] were calculated.

Ethical issues

The Ethics Committee of Iran University of Medical Sciences approved the study protocol, which was conducted in accord with the tenets of the Declaration of Helsinki. All participants signed a written informed consent.

Results

In this study, each test was performed by 33 participants aged 25.21 ± 6.229 years (mean ± SD). Thirty-three

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amblyopic eyes and 33 normal eyes were tested. Amblyopic eyes had visual acuity of 0.21 ± 0.101 logMAR and refractive error of +1.79 ± 2.93 spherical equivalent (mean ± SD), and normal eyes had visual acuity of 0.0 ± 0.0 logMAR and refractive error of +0.73 ± 1.45 spherical equivalent (mean ± SD). The mean results of FrACT and Metrovision tests are shown in Table 1. FrACT measurements were generally greater. As shown in Fig. 1, except for 1 cpd in amblyopic eyes, the difference of the means of the two tests was significant at all spatial frequencies in both amblyopic and normal eyes ($P < 0.01$). We also found significantly higher FrACT AULCSF values in both normal and amblyopic eyes ($P < 0.05$). This difference was more prominent in normal eyes ($P < 0.001$). The highest inter-test difference was observed at 5 cpd spatial frequency in normal eyes (0.496 log units), and the lowest inter-test difference was seen at 1 cpd in amblyopic eyes (0.026 log units).

As shown in Table 2, except for 5 cpd in normal eyes and 1 cpd in amblyopic eyes, Spearman's rho correlation test confirmed a correlation between FrACT and Metrovision at all spatial frequencies in both normal and amblyopic eyes ($P < 0.05$). Spearman's rho correlation test showed a significant correlation between AULCSFs obtained from the two tests in both amblyopic eyes ($P = 0.012$) and normal eyes ($P = 0.019$).

Graphical analyses of the difference against mean (Bland−Altman) are illustrated in Fig. 2. The difference between contrast sensitivity measurements of the two tests (FrACT-Metrovision) is plotted against the average of measurements ((FrACT+Metrovision)/2) for each spatial frequency. We evaluated the degree of disagreement and tendency for the difference between the two tests via this analysis. The lowest difference between contrast sensitivity measurements of the two tests was found at 1 cpd spatial frequency in amblyopic eyes which was −0.03 log units, and the highest difference between the two tests was at 5 cpd in normal eyes (0.50 log units). The narrowest limits of agreement were found at 3 cpd spatial frequency in normal eyes, and the widest limits of agreement were found at 5 cpd.

The best agreement between FrACT and Metrovision was found at 3 cpd in normal eyes; the difference between the findings of the two tests had the least variation for all the contrast sensitivity measurements at this spatial frequency ($r^2 = 0.002$, $P = 0.818$). After that, the two tests had an almost similar agreement at 5 cpd in normal eyes. The difference between the two tests tended to increase with contrast sensitivity at 1 cpd in normal eyes ($P = 0.013$) and all spatial frequencies in amblyopic eyes ($P < 0.01$). The two tests had an agreement in normal eyes when we assessed the AULCSF ($r^2 = 0.001$, $P = 0.842$) whereas there was no agreement in amblyopic eyes ($r^2 = 0.414$, $P < 0.001$).

Normal eyes had significantly higher contrast sensitivity in comparison to amblyopic eyes on both tests except for the result of Metrovision at 1 cpd ($P < 0.001$) (Fig. 3). Comparison of AULCSF between normal and amblyopic groups also showed higher values in the normal group on both FrACT and Metrovision tests ($P < 0.001$).

Table 2
Spearman's rho correlation between FrACT and Metrovision tests.

	Amblyopic eyes			Normal eyes		
Spatial frequency	1	3	5	1	3	5
Correlation coefficient	0.276	0.446	0.484	0.472	0.377	0.135
P value	0.120	0.009	0.004	0.006	0.030	0.450

Table 1
Mean (SD) contrast sensitivity (log unit) at each tested spatial frequency and the comparison between the two tests.

		Amblyopic eyes			Normal eyes		
Spatial frequency		1	3	5	1	3	5
Mean (SD)	FrACT	1.96 (0.31)	2.23 (0.46)	2.03 (0.51)	2.19 (0.37)	2.66 (0.18)	2.59 (0.25)
	Metrovision	1.98 (0.17)	2.03 (0.20)	1.79 (0.33)	2.05 (0.21)	2.21 (0.18)	2.09 (0.23)
P value (T Test)		0.618	0.007	0.006	0.028	0.000	0.000

SD: Standard deviation.

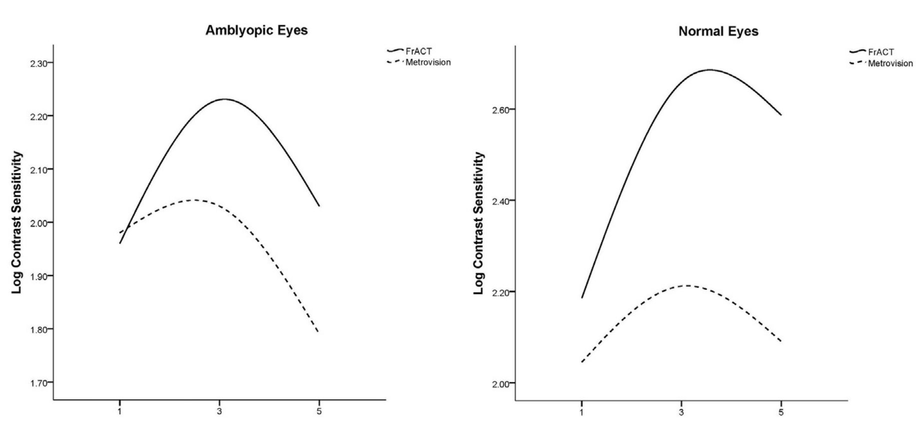

Fig. 1. Contrast sensitivity function (CSF) of FrACT and Metrovision tests in normal and amblyopic eyes.

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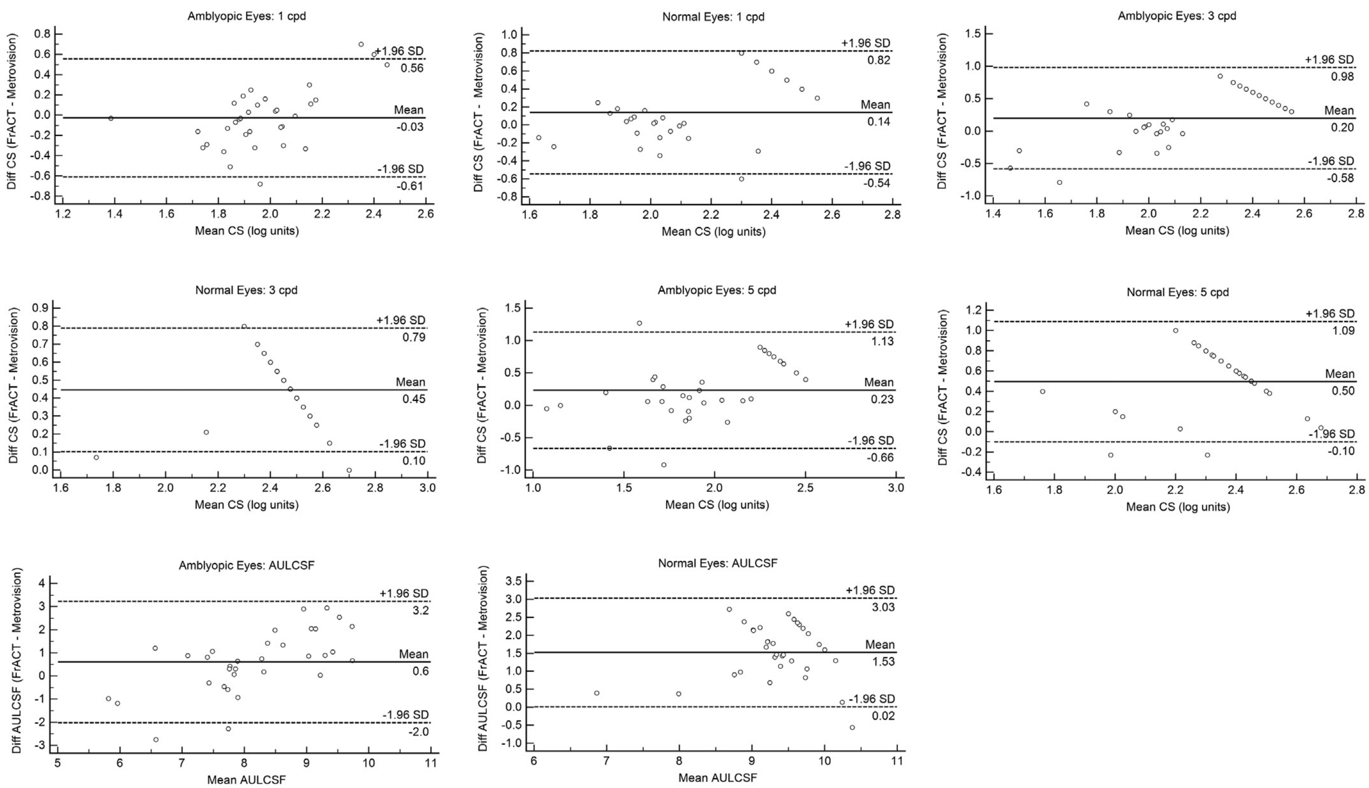

Fig. 2. Graphical analysis of difference versus mean contrast sensitivity (Bland–Altman) for all tested spatial frequencies and for area under logarithm of contrast sensitivity function (AULCSF). The solid line represents the mean difference between the two tests, and the dashed lines represent the limits of agreement (mean ± 2SD).

Discussion

In both normal and amblyopic groups, FrACT measurements were significantly ($P < 0.01$) higher than Metrovision readings at all spatial frequencies except for 1 cpd in amblyopic eyes. One of the reasons may be the higher background brightness of FrACT stimuli that could result in higher contrast sensitivity responses.[9] FrACT stimuli were displayed by a conventional LED monitor, and there was no brightness standard recommended by the manufacturer or other investigators for the test. Therefore, it was not possible for us to standardize the test in terms of luminance. The interaction between screen brightness and stimulus contrast may alter contrast sensitivity responses.[4] Increased contrast sensitivity with luminance is more prominent at high spatial frequencies.[1] This is consistent with our results as we found the greatest differences between the two tests at 5 cpd in amblyopic and normal eyes. Moreover, increased retinal illumination leads to more miosis, and the resulting pinhole effect improves modulation transfer function (MTF) and consequently contrast sensitivity.[10]

Metrovision uses stimuli with increasing contrast. Gratings are displayed for a short time at each contrast level, and the

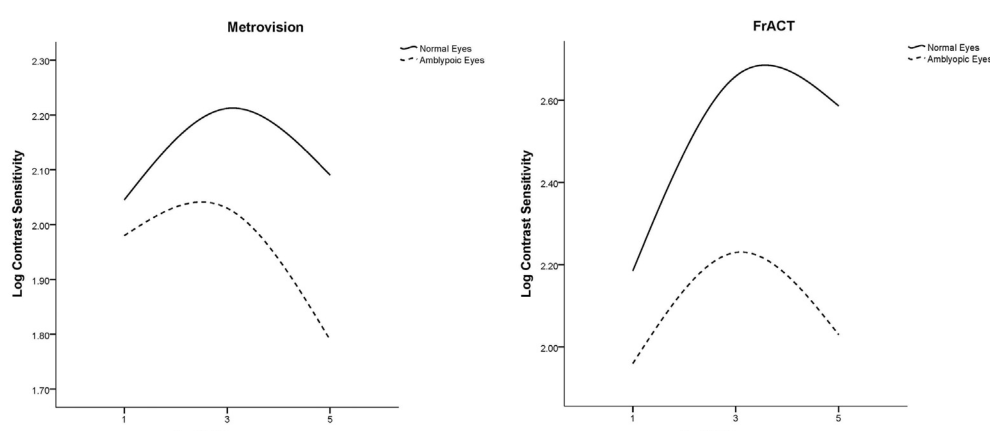

Fig. 3. Contrast sensitivity function (CSF) of normal and amblyopic eyes obtained from FrACT and Metrovision tests.

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stimulus contrast increases rapidly. Although we set a short time for stimulus exposure for FrACT (3 s), it was still longer than the duration of Metrovision stimulus exposure. Since increasing exposure duration improves contrast sensitivity,[11] we expected higher FrACT responses. The effect of longer exposure duration on contrast sensitivity improvement increases with spatial frequency,[11] which is in agreement with our findings as the difference between measurements of the two methods increased with increase in spatial frequency.

Adaptation and perceptual fading of the stimulus (Troxler effect) may diminish contrast sensitivity.[12] Metrovision displays gratings only in the vertical direction (unlike FrACT in which the direction of gratings changes during the test); so the observer experiences a more even stimulus. This facilitates fading and therefore reduces contrast sensitivity when tested by Metrovision.

Contrast sensitivity tests use different methods for displaying their stimuli including increasing contrast, decreasing contrast, and tracking (the stimulus contrast changes based on the observer's responses).[8] Metrovision uses increasing contrast, and FrACT uses the tracking method. One reason for higher responses recorded by FrACT may be the opportunity for re-displaying of the slides that are not correctly recognized by the observer, so the observer can correct his/her mistakes by the facility provided by the tracking method and Best PEST algorithm.[5] Metrovision also automatically displays the stimuli three times, but the repeated trials start from a contrast level around the previously recorded threshold (not from the beginning) that may result in underestimation of contrast sensitivity scores.

At 1 cpd, we found the lowest difference between the two tests in both normal and amblyopic eyes. The reason may be the truncation effect. A grating with a specific spatial frequency contains fewer cycles when displayed in a small field. This is more prominent for low spatial frequencies. The two-degree field of the FrACT stimulus holds only 2 cycles of a grating at 1 cpd. Reduced number of cycles per stimulus field leads to a drop in contrast sensitivity.[1,2] Thus, the stimulus field size affects contrast sensitivity. By increasing the stimulus field size up to 6.5°, the sensitivity improves rapidly, especially at low spatial frequencies.[8] Thus, the 10-degree field of the Metrovision stimulus may improve sensitivity responses at low spatial frequencies. Increased sensitivity due to the larger field on Metrovision and decreased sensitivity due to the truncation effect on FrACT may lead to rather similar results of the two tests at 1 cpd.

Our results confirmed a correlation between the results of the two methods in both groups. Likewise, both tests showed a significant reduction in contrast sensitivity in amblyopic eyes that is in agreement with previous studies.[13–15] Nevertheless, since the difference between the results of these tests increases with contrast sensitivity in amblyopic eyes, it seems that these tests do not have a similar behavior in different conditions. Thus, we cannot interpret the measurements of the two tests in the same way. It is necessary to further assess these two tests and compare them with other psychophysical contrast sensitivity tests in order to establish a set of standards and find the best method for measurement of contrast sensitivity in amblyopic eyes.

In conclusion, our results showed that FrACT and Metrovision have different characteristics, and their results are not interchangeable. Since the results of the tests were different in amblyopic eyes, contrast sensitivity measurements may be interpreted differently when a patient is examined by either test. Thus, it is necessary to establish standards and general instructions for measurement of contrast sensitivity in amblyopic eyes in order to reduce test related effects. In addition, it is necessary to consider the differences when the findings of previous studies that used different methods for contrast sensitivity measurement are compared.

Since patients with visual acuities between 0.1 and 0.4 logMAR have mild amblyopia, we should be aware that deeper amblyopic eyes might respond differently to both tests, and our findings might not be generalizable for all amblyopic patients.

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