

Mesopic Contrast Sensitivity Functions in Amblyopic Children

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This study both measured and compared the mesopic contrast sensitivity function and the visual acuity in both normal and amblyopic eyes from amblyopic children using an ACV (visual acuity analyzer). Twenty one amblyopic children (mean age, 8.48 years; S.D., 1.68 years), 11 strabismic amblyopes and 10 anisometropic amblyopes, were tested. Based on a display of the standard optotypes, the minimal contrast level, at which the optotypes were correctly read for all sizes of displays from a distance of 1m, was measured. The contrast ranged from 1% to 99% and the spatial frequencies ranged from 0.6 to 30cpd using a Landolt ring composed of low (0.6-2.9 c.p.d.), intermediate (3.0-12.9 c.p.d.) and high level (13.0-30.0 c.p.d.) frequencies. As the visual acuity decreased, the mesopic contrast sensitivity function decreased along the contrast sensitivity axis. However, the peak sensitivity was noted at the same spatial frequencies. A comparison between the normal eye and the corresponding amblyopic eye showed that under mesopic conditions, the contrast sensitivity functions decreased more in the intermediate spatial frequencies than in the other spatial frequencies. The mesopic contrast sensitivity function decreased in the amblyopic eyes, which suggests the possibility of its use as an adjunct to an evaluation of amblyopia.

Key Words: Amblyopia, intermediate spatial frequencies, mesopic contrast sensitivity function

INTRODUCTION

The contrast sensitivity function is a valuable

test for both detecting and diagnosing various diseases and is of particular value in assessing amblyopia.¹⁻⁴ Because of its sensitivity in detecting the pathology in children and adults, it has good potential as a vision screening tool.^{5,6} Unfortunately, contrast sensitivity function testing is limited primarily to photopic conditions because of its difficulty in setting and difficulty in screening children younger than the age of 10 years due to their short attention spans. Traditionally, only the photopic contrast sensitivity function has been tested but the daily activities are also performed under mesopic luminance such as moonlight. The photopic contrast sensitivity functions usually originate from only the cone cells, while mesopic contrast sensitivity functions result from not only the cone cells but also rod cells of the retina.⁷

The ACV (L2 informatique, France) Visual acuity analyzer was developed as a contrast sensitivity function test in the form of a sample optotype automatically developing various luminance levels and spatial frequencies. The contrast ranged from 1 to 99% and the frequency ranged from 0.6 to 30 cpd by a Landolt ring. The spatial frequencies were composed of low (0.6-2.9 c.p.d.), intermediate (3.0-12.9 c.p.d.) and high levels (13.0-30.0 c.p.d.). The ACV has stable displays, light levels with modern monitors, and contrasts up to 1%, except during the short time after the monitor is switched on. The true contrast was calculated as the ratio between two illuminance optotypes and a background as low as 0.1%, which is at least 10 times better than most of the other devices. Open field conditions without the use of eyepieces eliminates the induced optical myopia during testing. Variable test distances can

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stimulate not only the central part of the retina but also the periphery. The ease and simplicity of the ACV test makes it ideal for measuring the contrast sensitivity functions in children ≤ 10 years of age. The contrast sensitivity function under mesopic luminance in normal or amblyopic eyes has not been reported.

This study was designed to determine whether or not there are differences between the photopic and mesopic contrast sensitivity functions, and to establish the relationship between the childhood amblyopia and mesopic contrast sensitivity functions.

MATERIALS AND METHODS

Twenty one amblyopic children (mean age, 8.48 years; S.D., 1.68 years, 8 males and 13 females) consisting of 11 strabismic amblyopes and 10 anisometropic amblyopes were tested. The ethics committee of Severance Hospital approved both the consent form and study protocol. Informed consent for each child was obtained from at least one parent.

In the amblyopic patients, the eye with a difference of more than 1 Snellen line in the visual acuity compared to the other eye was included in the study. All the children underwent a full ophthalmic assessment, including a fundoscopy and refraction, in order to exclude other ocular pathologies. The examination of the strabismus included a measurement of the deviation angle for near (1/3 m) and distance (6 m) vision by an observer masked to previous examinations. The refractive errors of the amblyopic eyes and their fellow eyes were properly corrected by the lens in order to achieve the best visual acuity. The best corrected distance visual acuity was recorded using a Snellen distance visual acuity chart and was converted into its logMAR equivalent, as described by Ferris, et al.⁸ The visual acuity of the amblyopic eyes was 0.50 ± 0.21 logMAR, while the visual acuity of the normal eyes was 0.014 ± 0.053 logMAR.

The contrast sensitivity functions were measured with ACV consultants. Based on a display of the standard optotypes, this study measured the minimal contrast level at which the optotypes

were correctly read for all sizes of displays; from low to high spatial frequencies from a distance of 1m. Using the three alternative forced choice test, the patient simply reports on the opening orientation of the Landolt ring, and the patient's contrast sensitivity is considered to be the last point where the patient can correctly identify the opening orientation. A contrast sensitivity function was automatically determined by the contrast sensitivity measured at each spatial frequency. The spatial frequency or size was measured along the horizontal axis and the contrast sensitivity was measured along the vertical axis. The typical output of this test was a result curve showing the relation between spatial frequency and contrasts level, beginning at low frequencies, reaching a maximum at the intermediate frequencies, and decreasing progressively towards the high frequencies at both mesopic and photopic conditions. The photopic condition is a luminance between 1-4 ($\log\text{cd}/\text{m}^2$), while the mesopic condition is a luminance between -2.5-1 ($\log\text{cd}/\text{m}^2$). Parts of the curve below the minimal levels indicate established trouble, which were analyzed by specialists. The contrast levels may vary from 1% to 100%. They follow an exponential repartition, which ensures the precise exploration of the low contrast zone. The 1% contrast and a 100% contrast levels can only be displayed with properly calibrated quality monitors. The contrast sensitivity scores were recorded on ACV sheets and entered into a database that included the patient's age, visual acuity, diagnosis, and history of therapy. The data was later retrieved and converted to actual contrast sensitivity values and spatial frequency values and were submitted for statistical analysis. Both eyes were tested twice under both mesopic and photopic conditions. Patients were excluded from the study if they did not complete the four individual tests. Unless stated otherwise, the results of the two tests on each eye were averaged to give a single contrast sensitivity function.

The data was analyzed with a paired t-test of the SAS (statistical analysis system) program.

RESULTS

The photopic contrast sensitivity at the low

frequencies was 37.37 ± 4.13 dB in the normal eye and 35.83 ± 6.50 dB in the amblyopic eye. The photopic contrast sensitivity at the intermediate frequencies was 25.08 ± 9.04 in the normal eye and 18.54 ± 10.13 dB in the amblyopic eye ($p=0.027$). The photopic contrast sensitivity at the high frequencies was 4.75 ± 5.34 dB in the normal eye and 2.23 ± 3.52 dB in the amblyopic eye (Table 1). The peak contrast sensitivity in the normal eyes was noted at 1.5 c.p.d., while the peak contrast sensitivity in the amblyopic eyes was 0.6 c.p.d. (Fig. 1 and 2). As the visual acuity decreased, the photopic contrast sensitivity function decreased along the contrast sensitivity axis, but the peak sensitivity was located near the same spatial frequencies (Fig. 3). The mesopic contrast sensitivity at the low frequencies was 29.57 ± 3.59 dB in the normal eye and 27.94 ± 3.51 dB in

the amblyopic eye. The mesopic contrast sensitivity at the intermediate frequencies was 18.88 ± 5.80 in the normal eye and 12.39 ± 6.91 dB in the amblyopic eye ($p=0.001$). The mesopic contrast sensitivity at the high frequencies was 2.89 ± 3.38 in the normal eye and 2.53 ± 3.48 dB in the amblyopic eye (Table 1). The peak contrast sensitivity of both the normal and amblyopic eyes was noted at 0.6 c.p.d. (Fig. 4 and 5). As the visual acuity decreased, the mesopic contrast sensitivity function also decreased along the contrast sensitivity axis, and the peak sensitivity was located at the same spatial frequencies (Fig. 6).

DISCUSSION

There have been many studies on the contrast

Table 1. Contrast Sensitivity Function of Normal and Amblyopic Eyes under Photopic and Mesopic Luminance

Spatial frequency (cycle/degree)	Luminance (log candle/m ²)	Normal (dB)	Amblyopia (dB)	p-value
Low (0.6-2.9)	photopic	37.37 ± 4.13	35.83 ± 6.50	0.123
	mesopic	29.57 ± 3.59	27.94 ± 3.51	0.089
Intermediate (3.0-12.9)	photopic	25.08 ± 9.04	18.54 ± 10.13	0.027*
	mesopic	18.88 ± 5.80	12.39 ± 6.91	0.001*
High (13.0-30.0)	photopic	4.75 ± 5.34	2.23 ± 3.52	0.072
	mesopic	2.89 ± 3.38	2.53 ± 3.48	0.716

* $p < 0.05$.

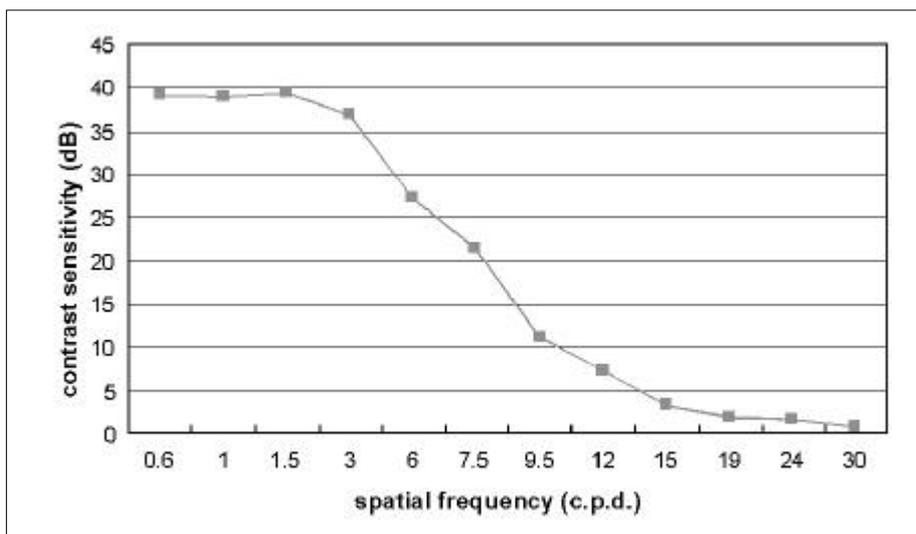


Fig. 1. The photopic contrast sensitivity using the ACV method in normal eyes. The peak contrast sensitivity in the normal eyes was found at 1.5 c.p.d..

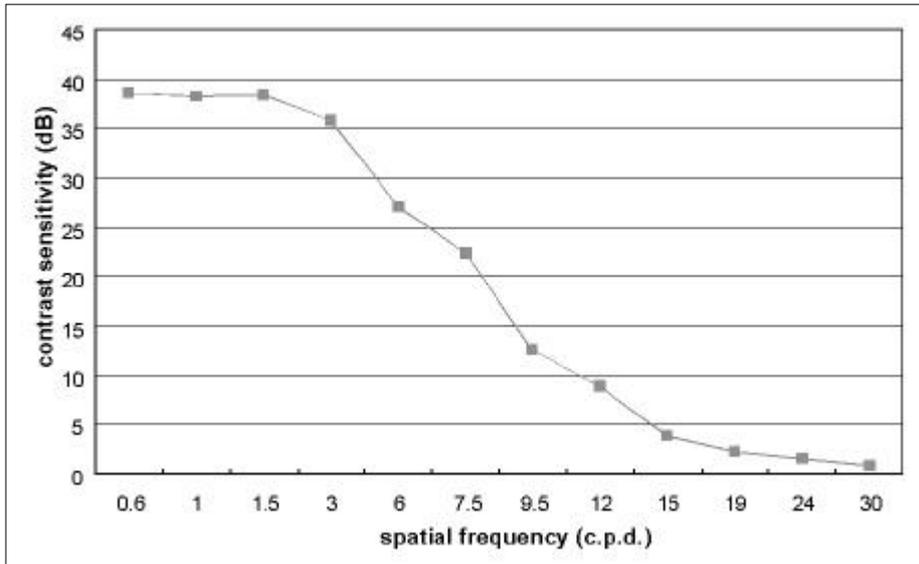


Fig. 2. The photopic contrast sensitivity using the ACV method in amblyopic eyes. The peak contrast sensitivity in the amblyopic eyes was found at 0.6 c.p.d..

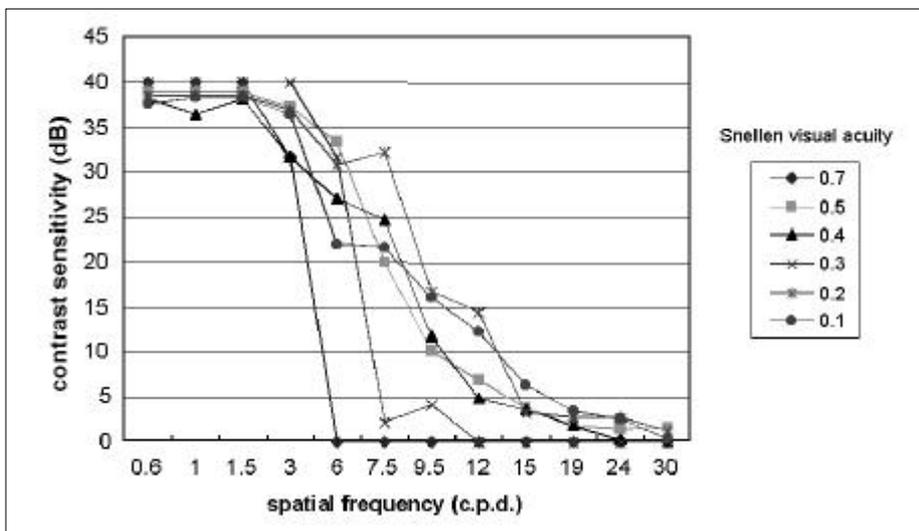


Fig. 3. The photopic contrast sensitivity using the ACV method in amblyopic eyes according to the change in the visual acuity. As visual acuity decreased, the photopic contrast sensitivity function decreased along the contrast sensitivity axis, but the peak sensitivity was located near the same spatial frequencies.

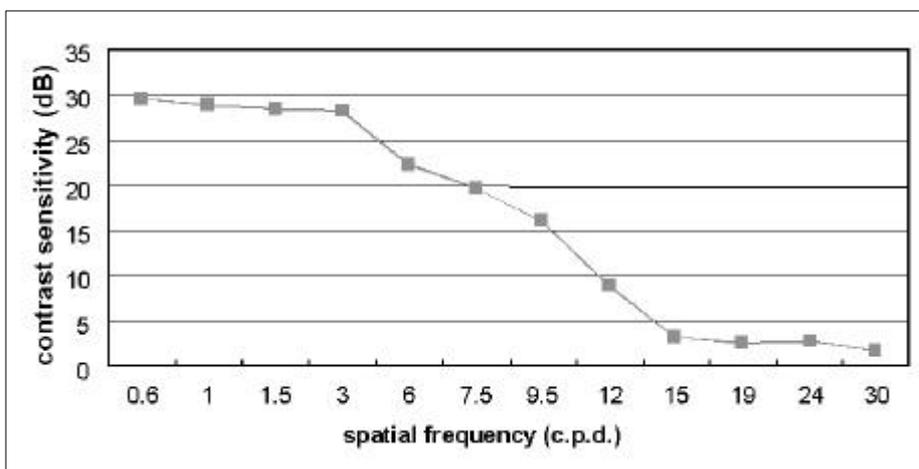


Fig. 4. The mesopic contrast sensitivity using the ACV method in normal eyes. The peak contrast sensitivity of normal eyes was noted at 0.6 c.p.d..

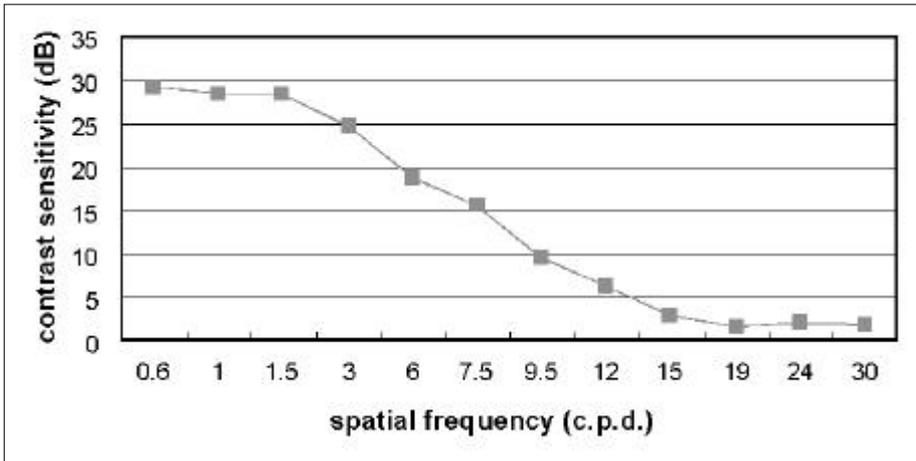


Fig. 5. The mesopic contrast sensitivity using the ACV method in amblyopic eyes. The peak contrast sensitivity of amblyopic eyes was noted at 0.6 c.p.d..

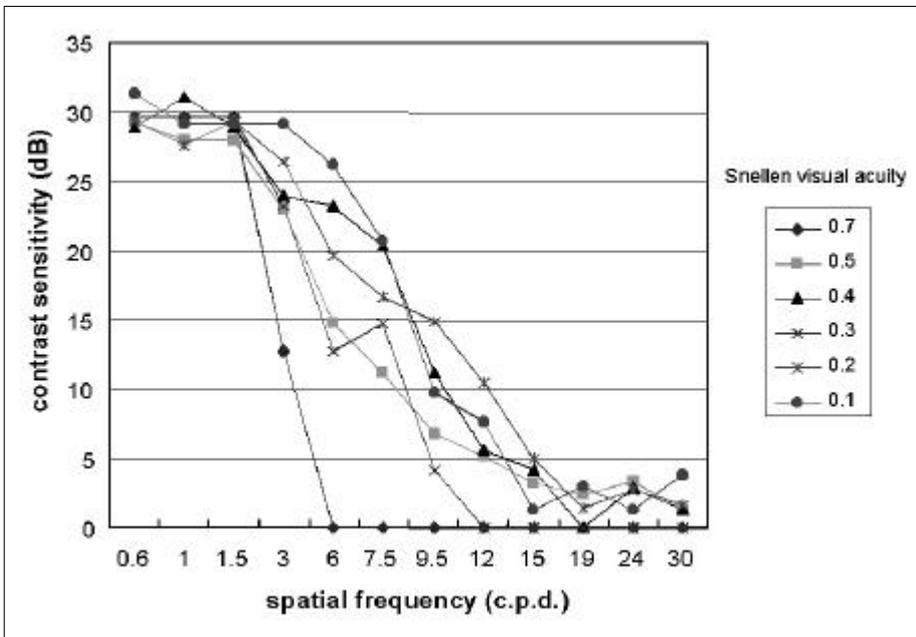


Fig. 6. The mesopic contrast sensitivity using the ACV method in amblyopic eyes according to the change in the visual acuity. As the visual acuity decreased, the mesopic contrast sensitivity function decreased along the contrast sensitivity axis, and the peak sensitivity was located at the same spatial frequencies.

sensitivity functions in humans, but all were performed under photopic conditions. It is generally believed that the photopic contrast sensitivity is related to the amblyopic eye.^{9,10} On the other hand, Howell, et al. reported a poor relationship between photopic contrast sensitivity function and the visual acuity in the amblyopic eye.¹¹ They measured the contrast sensitivity by slowly increasing the stimulus contrast from below the threshold until the child reported seeing the gratings.

This method is known to underestimate the contrast sensitivity and minimize the detection of the contrast sensitivity differences between the

eyes. In this study, the photopic contrast sensitivity functions for the non-amblyopic eyes of the amblyopic patients were similar to those reported by others,¹⁰ while the peak sensitivity was observed at lower spatial frequencies in both the normal and amblyopic eyes than has been reported elsewhere.

The ACV could also measure the contrast sensitivity functions at the lower frequency level, which was very intriguing in that the peak contrast sensitivity was found to be approximately 0.6-1.5 c.p.d. This may result from the improvements in computerized instruments.

Hess and Howell classified the types of am-

blyopia according to the frequency level of the decreased contrast sensitivity, and they believed that there were different functional types of amblyopia.¹² The definitions of the frequency levels in many studies depend on the investigators. With the ACV method, the contrast sensitivity functions were measured at the three spatial frequency levels. The intermediate and high frequency levels of this study correspond to the high frequency level reported elsewhere. Large differences were observed in the contrast sensitivity function between the normal and amblyopic eyes in the intermediate frequency level.

This is the first report to measure the mesopic contrast sensitivity function of the normal and amblyopic eyes and relate the mesopic contrast sensitivity functions with the visual acuity in childhood amblyopia. The mesopic contrast sensitivity curve showed a similar pattern to the photopic contrast sensitivity curve. As the visual acuity decreased, the mesopic contrast sensitivity function showed a tendency to decrease along the contrast sensitivity axis, but there was no difference in the spatial frequency of the peak sensitivity. A comparison between the normal eye and the corresponding amblyopic eye showed that the contrast sensitivity functions decreased more in the intermediate spatial frequencies under mesopic conditions than under photopic conditions. It is conceivable that the mesopic contrast sensitivity is more useful for evaluating amblyopia.

The increase in the contrast sensitivity with age is in general agreement with earlier reports,¹³⁻¹⁵ who reported that the contrast sensitivity function gradually increased to the adult levels in the first decade of life. Therefore, this result suggests that the mesopic and photopic contrast sensitivity functions were easily measured in the normal and amblyopic eyes when the ACV was employed in childhood. Further research on the changes in the mesopic contrast sensitivity function during amblyopia therapy, which is related to the development of visual acuity recommended.

The two types of amblyopia differ in the visual physiology. However, the aim of this study was to examine the amblyopic condition (decreased visual acuity) in order to determine how it affects the mesopic contrast sensitivity functions. Studies on the mesopic contrast sensitivity functions

according to the causes of amblyopia may be helpful in understanding the physiology of the contrast sensitivity functions.

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