

Effect of target size, temporal frequency and luminance on temporal modulation visual fields

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Abstract

The effects of five target sizes (0.125, 0.25, 0.50, 1.0, and 2.0 degrees) and four temporal rates (1, 5, 10, and 15 Hz) on temporal modulation fields (TMF) were assessed in ten observers at 3.4 cd/m² and five observers at 10 cd/m². A decrease of sensitivity was found as eccentricity increased for a 40 deg visual field. This decline in sensitivity was greater for small target sizes and higher temporal rates. Increasing the luminance causes peripheral facilitation at lower temporal rates and a sensitivity improvement throughout the visual field at higher temporal rates. Small targets and high temporal rates benefit the most from a luminance increase. The relevance of the data to the clinical assessment of TMFs is discussed.

Introduction

The analysis of temporal sensitivity for uniform targets throughout the central visual field in glaucoma has increased in recent years with encouraging results¹⁻⁵. The use of temporal modulation can be particularly useful in visual diagnostics because it allows the measurement of temporal sensitivity for a potentially large number of frequencies⁶. It has been suggested that glaucoma may produce greater deficits at particular temporal frequencies^{7,8}. An extension of this approach is the analysis of temporal modulation fields (TMF) which essentially evaluates the temporal modulation sensitivity throughout the visual field. The present study analyzes the effect of several parameters on the sensitivity profile of normal observers with an emphasis on target sizes similar to those used in the clinical assessment of visual fields (Goldmann sizes I to V). The parameters of interest are: (1) different eccentricities within a 40 degree visual field, (2) target size, (3) temporal frequency, and (4) luminance levels (photopic and low-photopic/mesopic levels).

Methods

Subjects

Ten eyes of ten normal observers were used for one of two luminance conditions (3.4 cd/m²). The average age was 28.4 (SD = 4.33) with a range of 23 to 37 years. Five of these observers also participated in a second luminance condition (10 cd/m²). All ten were experienced psychophysical observers and had undergone similar visual field testing procedures.

Apparatus

The display consisted of a 40x30 cm RGB monitor (Gigatek - 1931 cc) equipped with a medium persistence P22 phosphor. The monitor was modified to allow, under software control over the timing of the vertical sinc pulse, a 120 Hz non-interlaced full-screen refresh rate (255 lines with 560 pixels per line) and a 240 Hz half-screen refresh rate. At 5 Hz temporal frequency,

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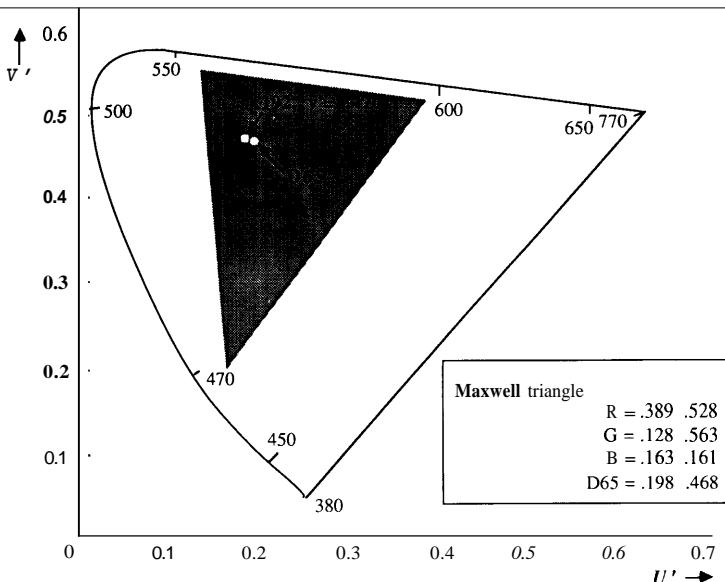


Fig. 1. CIE 1976 $u'v'$ chromaticity diagram. The Maxwell triangle specifies the chromaticities available on the video monitor. The dimensions of the Maxwell triangle in $u'v'$ units are given in the highlighted box. The two white dots in the triangle represent the whites used for this study.

this allows a sampling of 24 points on a sinusoidal function for the entire screen and 48 points for a half-screen.

No linearity or independence of the guns was assumed. A large range of DAC values was examined by measuring their chromaticity in CIE 1976 u', v' units (see Fig. 1) and their luminance output using a chroma meter (Minolta CL-100). The luminance was derived by comparing the illuminance output of the chroma meter and comparing it with a value obtained from a photometer reading (Spectra Spotmeter UBD-1/2). The range of DAC values was split into 10 steps (11 samples) for each gun and the 1331 combinations were evaluated. Two hundred and five combinations were eliminated because the luminance values fell into a range where the chroma meter becomes unreliable. With the measurements obtained from the remaining 1126 combinations a function for each gun was established which is used to extrapolate throughout the whole possible chromaticity range of the monitor represented by the Maxwell triangle obtained from actual measurements of the individual gun outputs. The Maxwell triangle for the monitor is shown as the grey area in Fig. 1 with the measurements listed.

Two mean luminance levels (3.4 cd/m^2 and 10 cd/m^2) were used in the following experiments. For the lower luminance level, a D65 white was used which represents the coordinates: $u' = 0.198$; $v' = 0.468$. For the second luminance level a slightly different white with the coordinates: $u' = 0.192$; $v' = 0.470$ was used. The reason is that it was impossible to obtain 100% modulation depth for 10 cd/m^2 at D65 because of the fine chromaticity sampling of the monitor (maximum luminance was 18 cd/m^2). With a slight change in u', v' values a 21 cd/m^2 maximum luminance was measured allowing us 100% modulation at 10 cd/m^2 mean luminance. Both whites relative to the CIE chromaticity diagram are shown as two adjacent white dots in Fig. 1.

The monitor was interfaced with graphics boards (Matrox - PG641) under the control of a 80386 IBM AT compatible computer. Luminance during testing sessions was measured using a Spectra Spotmeter (UBD-1/2). A chin rest was used to immobilize the head and a joy stick was used for the subject response.

Procedure

For each luminance level five target sizes (0.125, 0.25, 0.50, 1.00, 2.00 degrees of visual angle which are similar to Goldmann sizes I to V) and four temporal rates (1, 5, 10, and 15 Hz) were evaluated throughout a 40 degree visual field. The display used is shown in Fig. 2. For every target-size/temporal-rate combination eight points for each of five different eccentricities

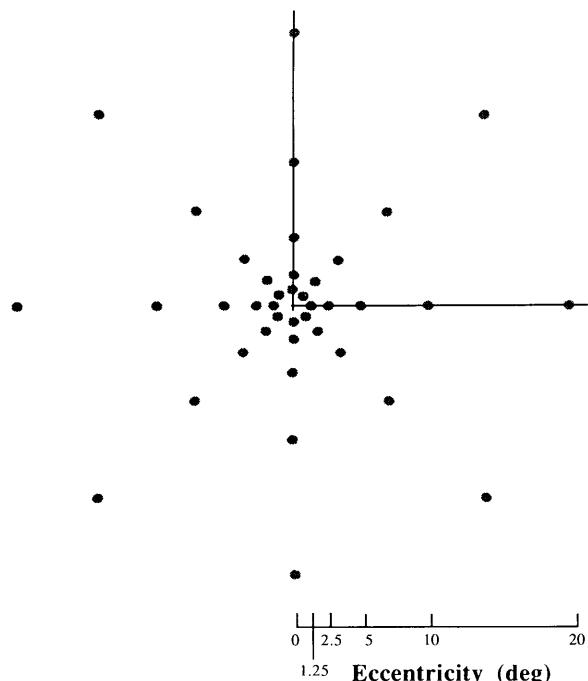


Fig. 2. Display of the 40 points that were assessed. The bottom scale shows the five eccentricities used in degrees of visual angle. The dark lines demonstrate that only one quadrant was presented at a time.

Temporal Waveform for 1 & 5 Hz % modulation

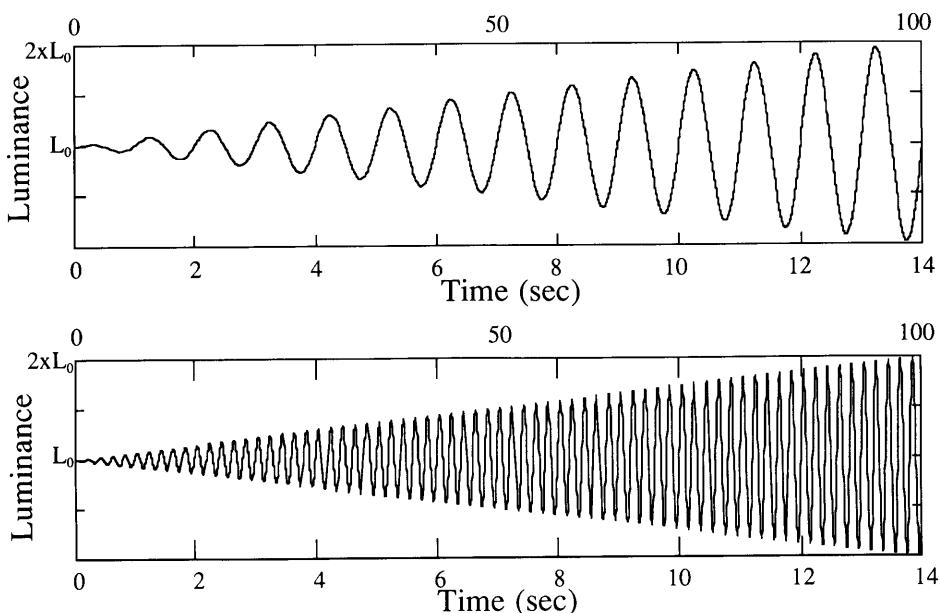


Fig. 3. Graphical representations of the luminance profile produced by the formula discussed in the text for a 1 Hz (top) and 5 Hz (bottom) temporal rate. L_0 = mean luminance. The top X-axis represents modulation depth and the bottom X-axis is time in seconds.

(1.25, 2.5, 5.0, 10.0, 20.0 degrees) were assessed for a total of 40 points in the visual field. The background screen was always kept at mean luminance. This maintains the surround at adapted levels to ensure accurate sampling of the target region.

The dependent measure was depth of modulation. To produce the stimulus, a slow temporal ramp was used which can be operationally defined as:

$$L(t) = [w(t) \times s(t) + 13 \times L_o]$$

where: $s(t) = \sin(2 \times \pi \times f_t \times t)$
and: $w(t) = t/14$

where L_o is the mean luminance, $s(t)$ the sinusoidal component, $w(t)$ the weighted function and f_t is the temporal frequency used. Graphical representations using these functions are shown in Fig. 3 for the 1 Hz and 5 Hz temporal conditions. Using such a slow onset avoids introducing abrupt temporal components in the stimulus which may interfere or interact with the temporal properties under observation. A variable onset time which randomly varied between 0.5 to 3 seconds was used. That is, prior to a given trial, an auditory signal was given and the temporal ramp would start between 0.5 to 3.0 seconds after the tone as randomly determined by the program.

In a given session, the visual field was separated into quadrants. A quadrant was randomly selected and the observer was presented with a small red fixation point in one of the four corners of the screen. Within this quadrant, any one of the potential test points was randomly chosen and a particular target-size/temporal-rate combination for that point was randomly chosen (out of a possible 20 for each point). Then the trial was initiated. Once all the test points for this particular quadrant were evaluated another quadrant was selected.

The observers were tested for two quadrants per testing session with a total of two sessions for the five observers who did only one luminance condition and four testing sessions for the other five. At the 3.4 cd/m^2 mean luminance level, the observers were adapted for 20 minutes to the mean luminance prior to the testing session. All testing was done monocularly and a 67 cm viewing distance was used.

Other features

The software developed for this particular setup is very flexible. Any target size permitted by the screen dimensions can be produced. Other psychophysical procedures such as a forced-choice staircase or other types of staircases are available. For clinical use, eye monitoring techniques where fixation is systematically assessed during testing by presenting targets in the blind spot area can be used. Special replication criteria for points which deviate from established or estimated means are available. Other features are the production of two- and three-dimensional polar maps of individual or group data. It is also possible to filter edges using gaussian functions and to use background luminances and chromaticities of choice. Different temporal waveforms are available and it is possible to produce Gabor gratings for achromatic and chromatic stimuli.

Results

Figs. 4a to 4e show the log modulation sensitivity values by retinal eccentricity for five target sizes under the 3.4 cd/m^2 luminance condition. The Y-axis represents the modulation sensitivity, so higher values mean better sensitivity. The bars shown on all the graphs are standard error bars. Each function represents a different temporal rate. For every target size a decrease of temporal sensitivity with increasing eccentricity was found which confirms previous results using single target sizes^{8,9}. Increasing the size of the target reduces this peripheral drop-off and this is true for all temporal frequencies. The 5 Hz condition produces the best sensitivity levels and 15 Hz the worst sensitivity levels for all target sizes. These relationships only change in respect to the 1 and 10 Hz conditions. For the smaller targets (Figs. 4a and 4b) the 1 Hz and 10 Hz sensitivity functions are similar. With increasing target size (Figs. 4c to 4e) this relationship changes where the 1 and 10 Hz functions separate. Ultimately the 10 and 5 Hz temporal rates are alike and the 15 and 1 Hz conditions have similar sensitivity profiles (see Fig. 4e). The only deviance from this general description is the 1 Hz function which never quite drops

Mean Lum. = 3.4 cd/m²

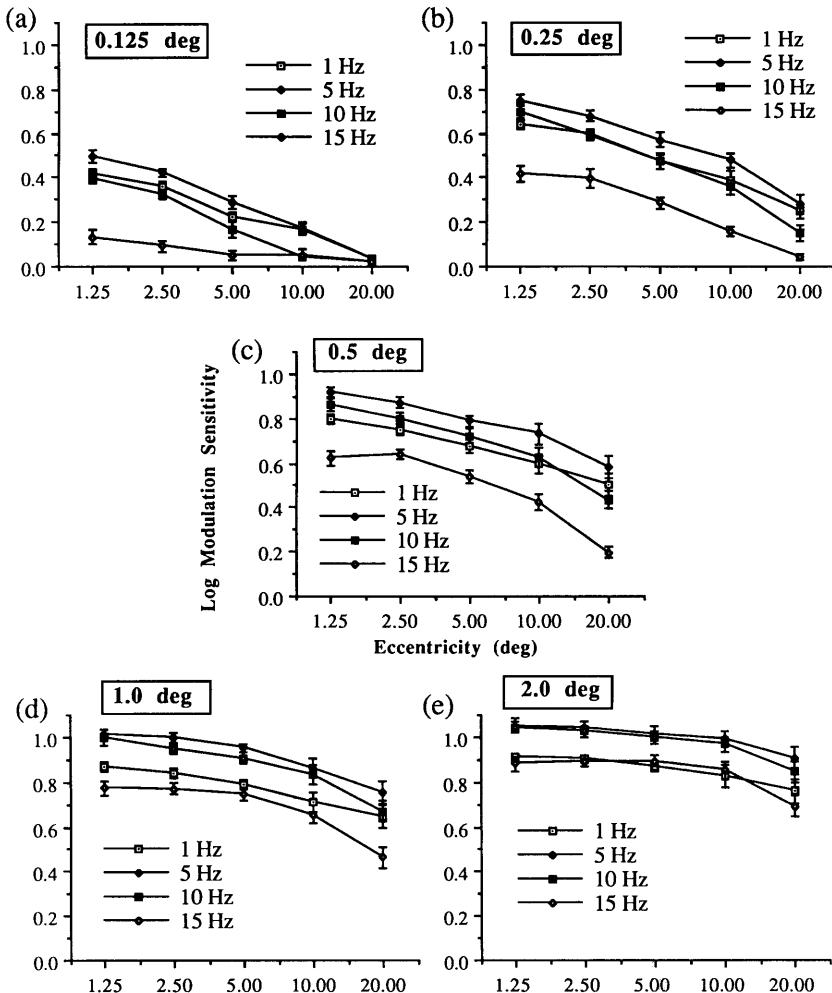


Fig. 4. Graphs for the five target sizes and four temporal rates obtained for the 3.4 cd/m² condition. The Y-axis represents log modulation sensitivity and the X-axis represents retinal eccentricity.

off in sensitivity from 10 to 20 degrees eccentricity as do the functions obtained for the other temporal rates. This is true for all but the smallest target size (0.125 deg). This effect is not evident for the smallest target because of a ceiling effect at 20 degrees eccentricity.

Figs. 5a to 5e show the log sensitivity values by retinal eccentricity for the different target sizes under the 10 cd/m² condition. A similar drop-off by eccentricity as for the previous luminance is observed. The 5 Hz temporal condition still produces the best sensitivity except for the largest target (Fig. 5e) where the 5 and 10 Hz conditions show identical functions. The 15 Hz condition, however, does not produce the lowest sensitivity for all target sizes as shown for the previous luminance level. For the 2.00 deg target size (Fig. 5e) the sensitivity profile is actually higher than that for 1 Hz. Again the 1 Hz function does not drop as fast as the other temporal rates especially at the two largest target sizes where the 1 Hz function is literally flat (Figs. 5d and 5e).

Mean Lum. = 10 cd/m²

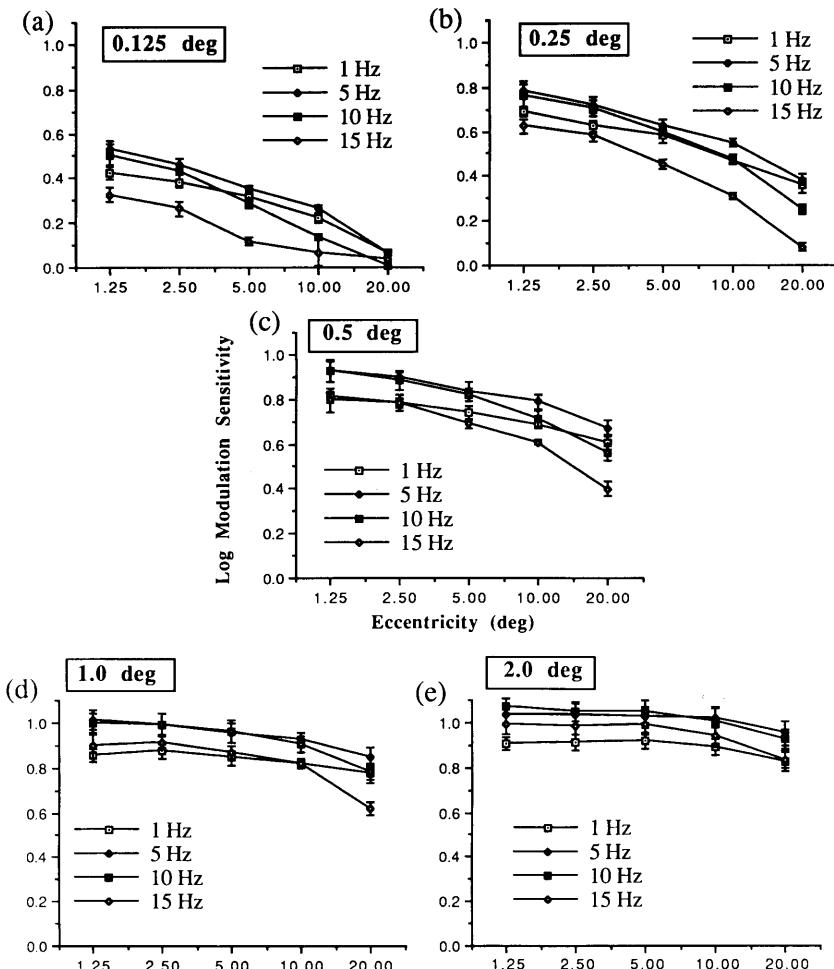


Fig. 5. Graphs for the five target sizes and four temporal rates obtained for the 10 cd/m² condition. The Y-axis represents log modulation sensitivity and the X-axis represents retinal eccentricity.

Perhaps the best way to determine the beneficial or detrimental effects of luminance changes is to compare the sensitivity profiles obtained under the different luminance levels directly, which is what has been done in Figs. 6 to 10. In each of these figures, the graphs a, b, c, and d correspond to the 1, 5, 10 and 15 Hz conditions. The higher luminance level is represented by the closed symbols and the lower luminance by the open ones. In Fig. 6, which represents the data for the 0.125 degree target, a luminance increase from 3.4 cd/m² to 10 cd/m² mean luminance produces benefits at eccentricities of five degrees onward for the two slower temporal rates (not evident at 20 deg because of a ceiling effect). An increase in sensitivity is apparent for all eccentricities at the higher temporal rates (10 and 15 Hz) until a ceiling effect at 10 and 20 degrees eccentricity is reached. The same pattern is evident in Fig. 7 (size 0.25 deg) where graphs (a) and (b) show improvements from five degrees on and graphs (c) and (d) throughout the visual field except for 20 degree eccentricity at 15 Hz where a ceiling effect is again observed. A similar pattern is observed in Figs. 8, 9 and 10, except that the effect of

Target Size 0.125 deg(I)

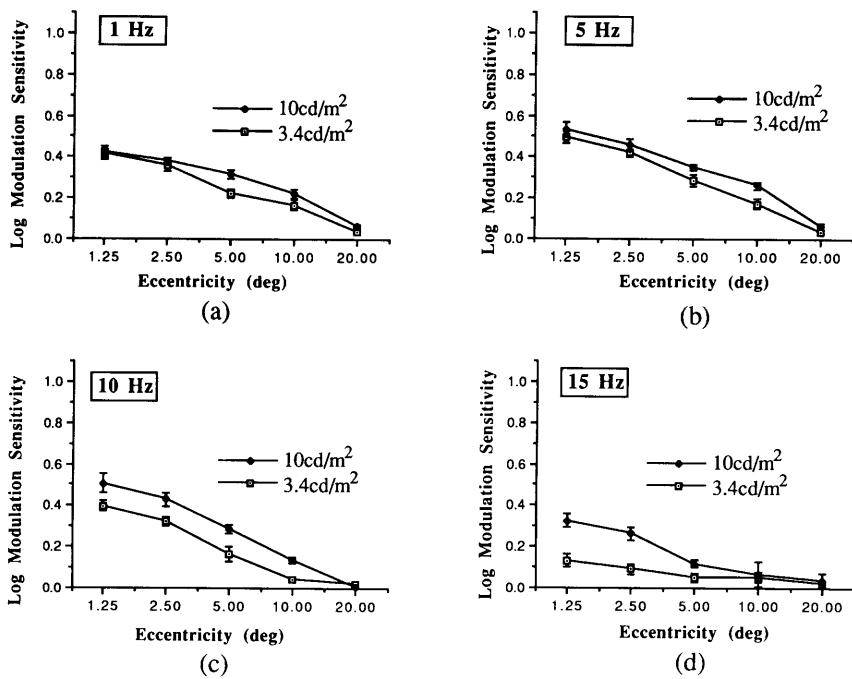


Fig. 6

Target Size 0.25 deg(II)

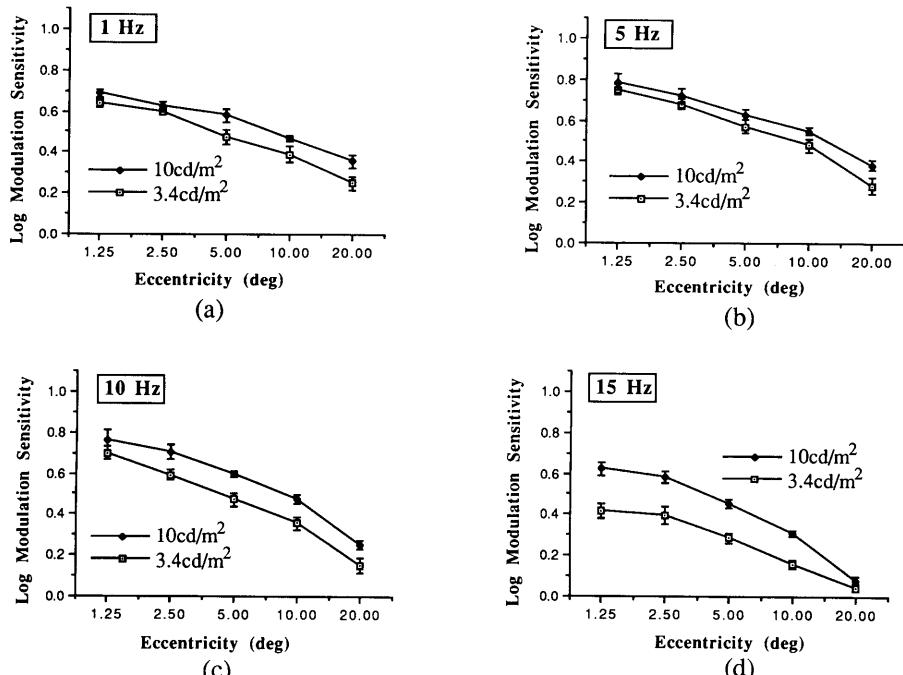


Fig. 7

Target Size 0.5 deg(III)

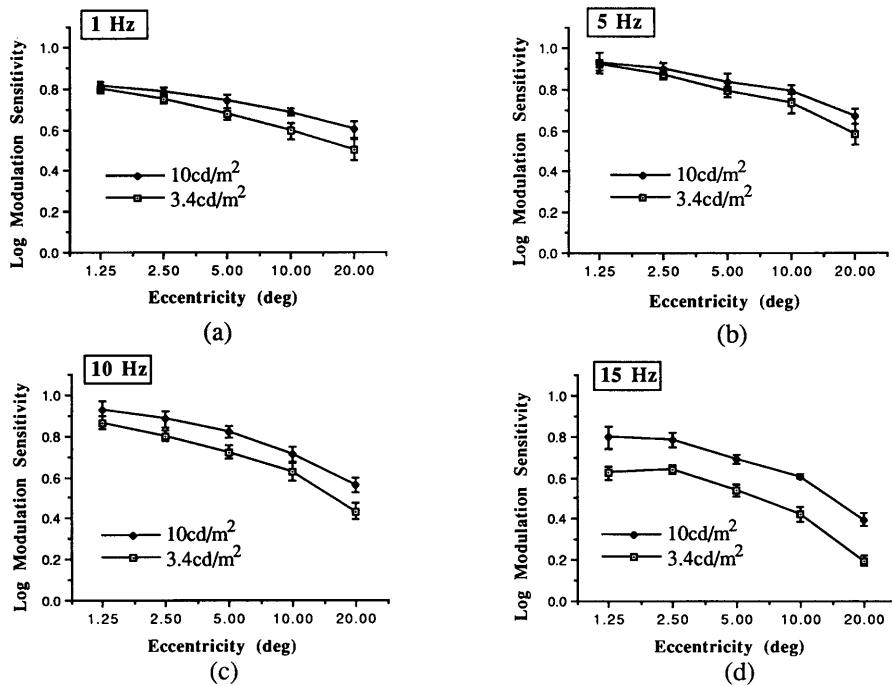


Fig. 8

Target Size 1.0 deg(IV)

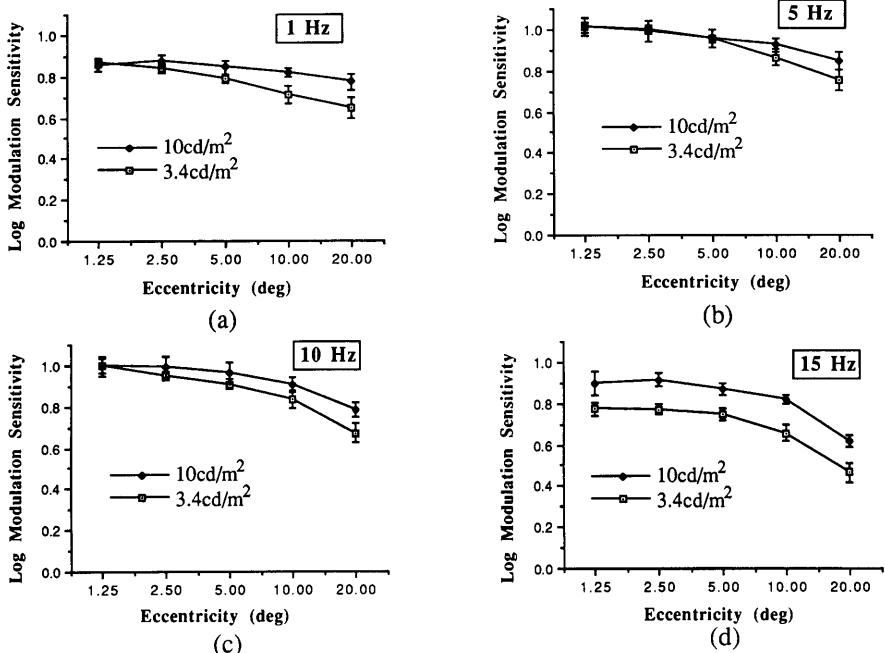
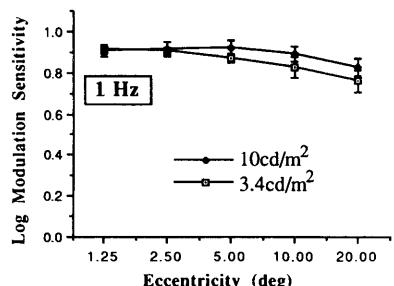
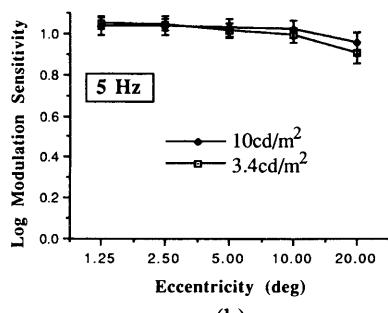


Fig. 9

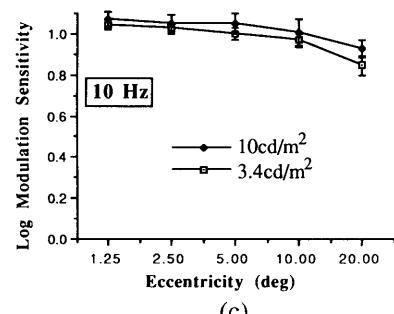
Target Size 2.0 deg(V)



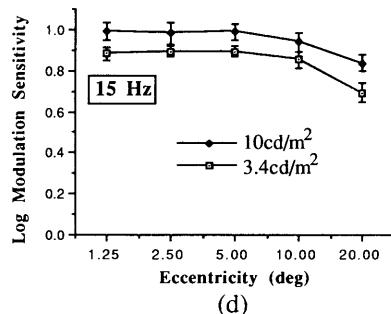
(a)



(b)



(c)



(d)

Fig. 10

Figs. 6 to 10. Sensitivity profiles obtained from both luminance conditions for all parameters. Target sizes 0.125 to 2.0 deg correspond to Figs. 6 to 10, respectively. Please see text.

higher luminance diminishes with increasing target size to the point where it is almost nonexistent at the 2.00 degree target (Fig. 10). Only the 15 Hz condition seems to have benefitted from the luminance increase at this target size.

Conclusions and discussion

A 5 Hz temporal rate generally produces the best sensitivity values and this is true for both luminance conditions. Further, there is less of a drop-off of sensitivity as the target sizes increase for all temporal-rate/luminance combinations.

Mean luminance seems to interact with target size and temporal frequency. Firstly, the larger the target the less facilitation is obtained from increased luminance. Secondly, the higher the temporal rate the more the sensitivity is raised by a luminance increase. This second facilitation tends to spread from the peripheral areas towards the central points until all eccentricities measured show some facilitation at the higher temporal frequencies. This implies that the peripheral retina is more sensitive to luminance changes at low temporal rates and the luminance increase produces a better response throughout the retina at high temporal rates. The terms low and high temporal rates used here are relative to the present conditions. Under luminances higher than in the present study all the temporal rates reported here may be considered as low to medium temporal frequencies.

The results shown here also have relevance for the clinical application of temporal modulation fields. One intent of most types of visual field measurements is to use a relatively small target size to establish localized defects. What is obvious from these results is that the choice of target size is directly dependent on the temporal rate being assessed and the luminance level

used. If a fixed target size was to be used in the assessment of TMFs, one should use a size which allows for other factors such as loss of sensitivity due to the normal aging process. It may also be desirable to leave a range of sensitivity below normal thresholds which could be useful in the monitoring of visual disorders. Under the present conditions, if one desired to assess TMFs for high temporal rates (10 Hz or 15 Hz), the use of a one or two degree target size would be necessary. Thus, there is a trade-off between temporal rate and spatial resolution.

At least two different strategies can be used when implementing TMFs. One is to use a constant target size and the other is to increase target size in proportion to some magnification factor. An assumption that often underlies the second approach is that temporal modulation sensitivity does not vary as a consequence of different temporal mechanisms as one moves towards the periphery but is a result of the neural representation at the retinal ganglion cells in combination with luminous flux⁹. Other researchers emphasize the role of photoreceptors¹⁰. The point is that there are no easy solutions as to what magnification function should be used. One solution is to empirically determine which scaling function should be used under particular conditions. An analysis of this issue along with the subject of visual field asymmetries has been done and will be dealt with elsewhere¹¹. Generally, those results show that the scaling function cannot be made independent of luminance under low photopic/mesopic conditions.

The present results offer a reasonable building block upon which to establish what properties affect temporal modulation fields under luminance conditions where both rods and cones may be involved. A large number of implementations is possible in the assessment of TMFs in the clinical domain. Only empirical data will elucidate whether certain parameter combinations are more beneficial than others. What is certain is that TMF measurements have great potential particularly in the assessment of disorders such as glaucoma and optic neuropathies.

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