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Foveal and peripheral thresholds for detection and resolution of vanishing optotype tumbling E's

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Abstract

We measured detection and resolution acuity for vanishing optotype tumbling E stimuli in both the fovea and at 30° in the periphery to determine if peripheral resolution is sampling limited for this stimulus. In the fovea, where acuity is optically limited, detection and resolution were the same. At 30°, however, detection was markedly better than resolution indicating that peripheral resolution is sampling limited for this stimulus. Detection acuity was higher when contrast was 90% rather than 40%, but resolution did not change with contrast. The vanishing optotype is a legitimate perimetric stimulus to measure retinal ganglion cell density provided the task is resolution and not detection.

Keywords: Aliasing; Detection; Peripheral acuity; Resolution; Vanishing optotype

1. Introduction

'High-pass' acuity test characters, first described by Howland, Ginsburg and Campbell (1978) were developed in order to equalise detection and resolution thresholds in foveal vision. This is accomplished by having equal amounts of black and white in the stimulus in order that its mean luminance can be equated to the background. This kind of stimulus was termed a 'vanishing optotype' by Frisen (1986) because, when the mean luminance of the target is the same as the background, the thresholds for detection and resolution are very similar in foveal vision and the target 'vanishes' when it can no longer be resolved.

Frisen employed this kind of target as an acuity perimetry stimulus in the clinical test termed high-pass resolution perimetry (Frisen, 1987). He claimed that, since detection and resolution thresholds are the same, when we use the target peripherally we can estimate the resolution performance merely by measuring detection performance. This in turn should, it is claimed, give us an idea of the localised sampling density of the underlying retina, which could aid in the detection of conditions which cause death or dysfunction of ganglion cells such as glaucoma.

The above line of reasoning is not valid for two reasons. Firstly, detection and resolution thresholds have never been measured separately for this kind of stimulus in peripheral vision, so we have no way of knowing if they yield the same result. Secondly, the limits to detection and resolution are very different in the fovea and periphery.

Foveally, spatial frequencies higher than the resolution limit of the retina are attenuated by the optics of the eye (Campbell & Gubisch, 1966), so any spatial frequency that can be detected can simultaneously also be resolved. This explains the similarity between detection and resolution acuity in the fovea with this stimulus. In the periphery the situation is very different. The sampling density of the retinal ganglion cells deteriorates faster than the optical quality (Green, 1970; Millodot, Johnson, Lamont & Leibowitz, 1975; Thibos,

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Cheney & Walsh, 1987; Thibos, Walsh & Cheney, 1987; Curcio & Allen, 1990) and so it is possible for a stimulus of high spatial frequency to be detected in peripheral vision but not resolved. Thus, while the limiting factor for grating detection is ganglion cell receptive field size, the limiting factor for peripheral resolution of gratings is the sampling density of the retinal ganglion cells (Thibos et al., 1987). Further evidence for the sampling limited nature of peripheral resolution comes from the phenomenon of aliasing often perceived by subjects undertaking resolution tasks in peripheral vision (Williams, 1985; Smith & Cass, 1987; Thibos et al., 1987; Anderson, 1996) whereby a grating of high spatial frequency is perceived as one of lower frequency and a different orientation.

The vanishing optotype has similarities to an experimental grating stimulus in that it is designed to have the same mean luminance as the surround and yields similar performance for detection and resolution in the fovea. However, it also differs from a grating in that it contains a wide range of spatial frequencies. Many of these spatial frequencies may contain only a few cycles within the stimulus window, a factor which can significantly reduce both detection and, to a lesser extent, resolution performance over an extended grating (Anderson, Evans & Thibos, 1996). We wanted to measure detection and resolution thresholds for vanishing optotype characters in both foveal and peripheral vision in order to determine if resolution is sampling limited in the periphery for this type of stimulus in the same way as gratings, evidenced by a significant difference in performance for both tasks. This would indicate the validity of the stimulus as a perimetry target to measure localised retinal ganglion cell density.

2. Methods

2.1. Stimuli

Stimuli were 'high-pass' vanishing optotype tumbling E stimuli where the core of the character was black and the surround white, but the relative amounts of black and white were equal (Fig. 1). Stimuli were created by computer and transferred to 35 mm slide format where the stimulus in the centre occupied 10% of the total area of the slide. The image was projected by a zoom slide projector onto a white screen where the stimulus could be increased in size without change in focus. Contrast was either 90 or 40%, as verified on the screen, and the mean luminance was carefully equated with the background. This was verified by viewing the stimulus through a blur lens to look for an overall luminance difference between stimulus and background.

2.2. Psychophysics

We measured detection and resolution separately in the fovea and at 30° on two trained observers, one an emmetrope (RSA) and one a low myope (FAE) for stimuli of both contrasts. All measurements were undertaken with normal room illumination lighting switched on.

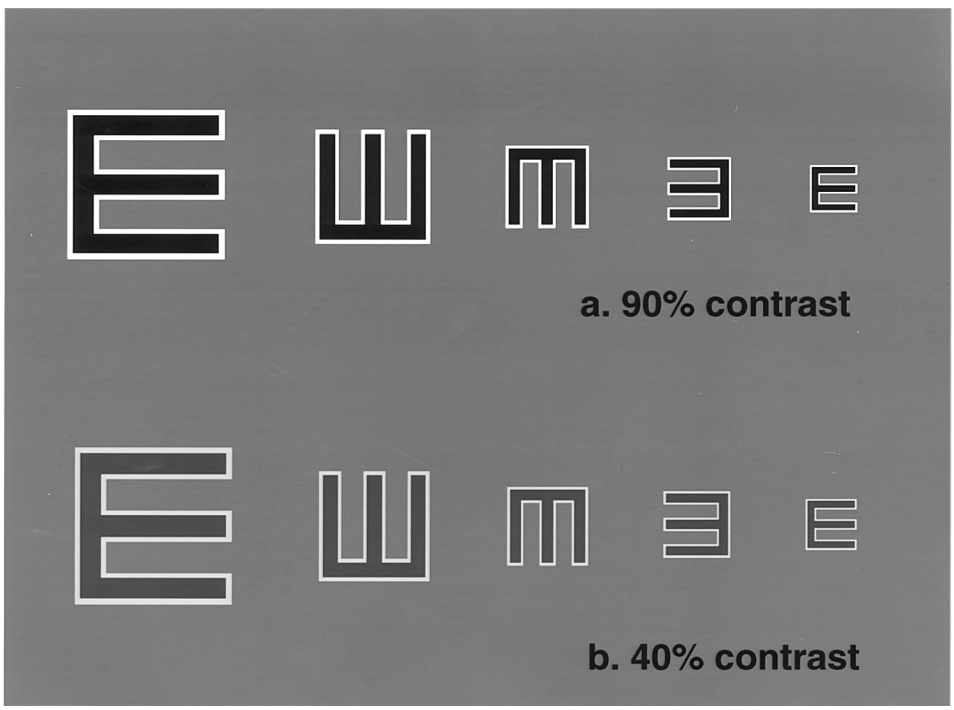

Fig. 1. The Tumbling E set of characters (90% and 40% contrast).

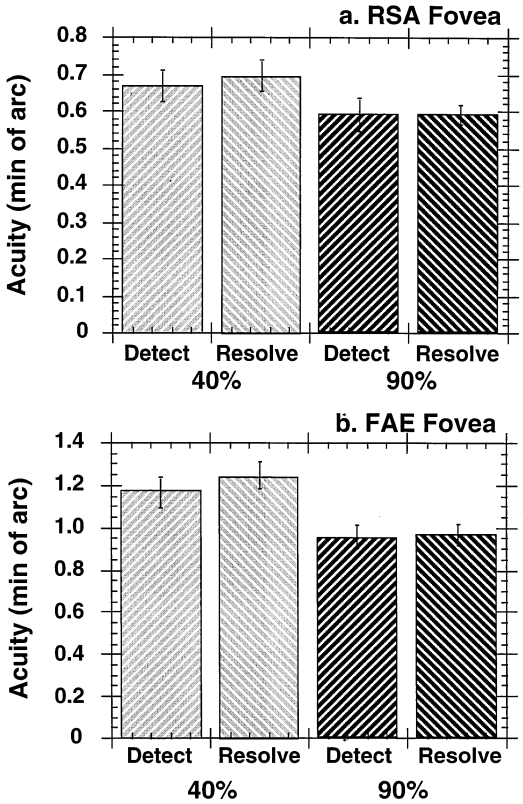

Fig. 2. Detection and resolution thresholds for high (90%) and low (40%) contrast stimuli in the fovea for both subjects.

For foveal measurements the subject viewed a white screen at 13 m on which the stimuli were projected from a projector placed 0.75 m away. Foveal refractive error was corrected at all times. An ascending method of limits strategy was employed to determine the threshold where the target was gradually increased in size from a sub-threshold starting size by means of the zoom lens of the projector, while focus remained sharp. For detection, the subject's task was to indicate when contrast was first present on the screen, and for resolution the task was to identify the orientation of the target, randomly presented as either right, left, up or down. Each trial took approximately 8 s and observers were encouraged to move fixation between trials to avoid Troxler fading effects. Stimulus size was measured with a ruler on the screen at each trial. In a session, ten measurements were taken for each randomly presented tumbling E orientation (40 presentations in all) for both detection and resolution, and threshold for each was calculated as the mean of the 40 measurements. This procedure was performed separately for stimuli of both contrasts.

For the peripheral measurements the subject fixated a spot at 3.5 m directly in front while observing the stimulus projected 3.5 m away at 30° in the horizontal temporal field. To keep the contrasts the same as the fovea the projector was again placed 0.75 m from the screen. The refractive error was first determined at the location in question, for each subject, using retinoscopy and the appropriate correction placed in a lens holder in line with the peripheral target at all times. For detection the subject's task was again to indicate the presence of contrast on the screen and for resolution the task was to identify the orientation of the target. Ten measurements were taken for each tumbling E orientation for both detection and resolution, and threshold was again calculated as the mean of the 40 measurements. As in the fovea, the measurements were made separately for both contrasts.

3. Results

Fig. 2 plots the foveal results for both subjects. Error bars represent ± 1 S.D from the mean of the 40 measurements for each threshold. It is clear that detection and resolution performance are both significantly better for the 90% contrast stimulus than the 40% contrast stimulus. It is also clear that detection and resolution acuity are not significantly different in foveal vision at either contrast.

The results for the 30° measurements are in Fig. 3. It can be clearly seen that detection acuity is significantly higher than resolution acuity at both contrasts, more so

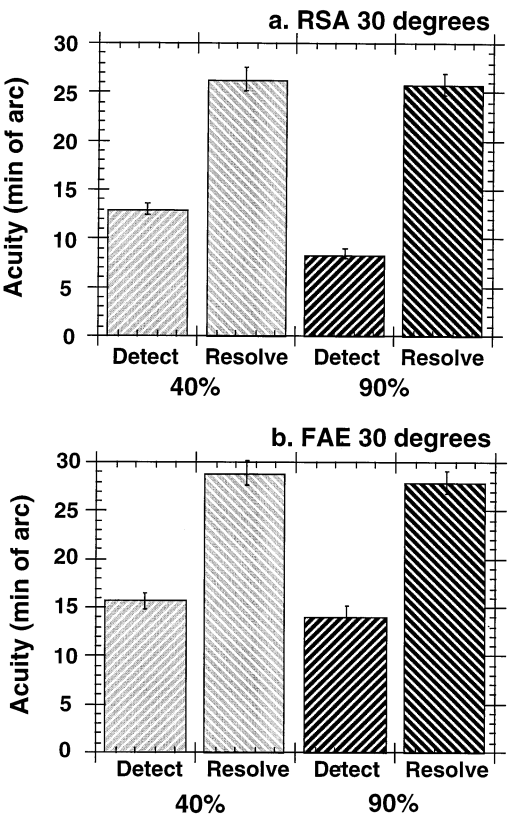

Fig. 3. Detection and resolution thresholds for high (90%) and low (40%) contrast stimuli at 30° in the periphery for both subjects.

for the high contrast stimulus. Detection acuity was better when the stimulus contrast was higher for both subjects, but resolution performance was unaffected by reduction in contrast to 40%.

4. Discussion

The close similarity of detection and resolution thresholds in foveal vision is in agreement with the results of Frisen (1986). The present stimuli behave as 'vanishing optotypes' in foveal view and can be readily resolved when they become detectable. Some small difference in performance for detection and resolution could reasonably be expected since the targets are not truly 'high-pass' so that even though they have the same mean luminance as the surround, some of their features will be detected shortly before the whole target can be resolved. However, the results indicate that foveal resolution is optically limited for these stimuli in that spatial frequencies higher than the resolution limit of the retina do not get through the optics of the eye.

The situation is, however, totally different in the periphery, where detection acuity is significantly higher than resolution acuity at both contrasts. This indicates that resolution performance for this kind of stimulus is limited by the ganglion cell sampling density in peripheral vision in much the same way as gratings, evidenced by the significant difference between detection and resolution acuity at 30° eccentricity.

Further evidence for the sampling limited nature of the resolution task comes from the observations of aliasing reported by both subjects throughout most of the experiment whereby the stimulus appeared to contain features of low spatial frequency at oblique orientations which were not physically present. Detection acuity displays significantly different performance in peripheral vision and is clearly limited by different factors.

Detection performance also declined with contrast, particularly for subject RSA, but resolution did not. This is in agreement with previous studies which indicate that resolution performance for gratings does not much change in peripheral vision until contrast falls to nearly 10% (Anderson, 1996; Thibos, Still & Bradley, 1996). This is further evidence that the resolution task is sampling and not optically limited in that a certain minimum level of contrast is required for optimum performance but increasing contrast beyond that has little or no effect on performance. We would expect the high contrast stimulus to be more robust to the effects of optical defocus for this reason.

In conclusion, the 'vanishing optotype' tumbling E is a legitimate stimulus for measuring retinal sampling density provided it is used peripherally and the task is truly resolution rather than detection. High-pass resolution perimetry (HRP) may, therefore, be wrongly named in that the subject is required to merely detect the stimulus; a task which yields a different threshold than resolution and does not appear to be sampling limited. The stimulus has potential to be used to separately measure detection and resolution performance in different forms of eye disease in order to better separate optical losses of vision from neural sampling ones. This may lead to the better detection an monitoring of conditions such as glaucoma. We advocate that the higher contrast target would be more appropriate for this purpose since, displaying a larger aliasing zone, resolution would be less susceptible to the effects of optical deficiencies.

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